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Comparison of Forest Stand Edges in Riparian and Mesic Habitats Along Watts Bar Reservoir Shoreline

Ruth Anne Hanahan
University of Tennessee, Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Ruth Anne Hanahan entitled "Comparison of Forest Stand Edges in Riparian and Mesic Habitats Along Watts Bar Reservoir Shoreline." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Ecology and Evolutionary Biology.

Clifford C. Amundsen, Major Professor

We have read this thesis and recommend its acceptance:

Carol Harden, John Rennie

Accepted for the Council:
<u>Carolyn R. Hodges</u>

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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and Dean of The Graduate School

COMPARISON OF FOREST STAND EDGES IN RIPARIAN AND MESIC HABITATS ALONG WATTS BAR RESERVOIR SHORELINE

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Ruth Anne Hanahan
December, 1996

DEDICATION

This thesis is dedicated to my parents
Marguerite V. Hanahan
and
Thomas D. Hanahan

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I would like to thank the people who have academically, financially and emotionally supported me in this research endeavor. I first thank my committee members, Dr. Cliff Amundsen, Dr. John Rennie, Dr. Carol Harden, for their timely reviews of, and helpful comments on, my thesis. I am particularly grateful to Dr. Amundsen who initially gave me the encouragement to enter the Ecology Program and later assisted in conceptualizing this research. I am appreciative of his sharing the gift and power of observation, a disappearing art and skill that is integral to understanding the relationships in field ecology. Our "front-porch" discussions and oftentimes bantering stimulated ideas and imparted knowledge and his entertaining stories alway kept me laughing.

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ABSTRACT

Approximately fifty years ago, the landscape upslope from the natural, riverine position banks of the Tennessee River was inundated by the closing of Watts Bar Dam. On the currently forested shoreline, habitats within the direct influence of the reservoir pool are riparian. Those above that influence are mesic. The purpose of this research was to determine compositional and structural differences between edges of mature forest stands established in a riparian habitat and those established in a mesic habitat along Watts Bar Reservoir shoreline.

Thirty quadrats were placed on shoreline sites with mature, minimally-disturbed forest stands: 15 in a riparian habitat and 15 in a mesic habitat. Riparian and mesic habitats were distinguished by the hydric influence of the depth-to-subsurface lateral pool flow. A habitat was identified as riparian if subsurface lateral pool flow was estimated to be less than 0.5 m to soil surface (i.e., a low-lying area) and mesic if greater than or equal to 0.5 m (a topographically-elevated area). Each quadrat was 4 m wide x 25 m long and was located along the pool with the lengthwise edge being the summer pool line.

Forest stand characteristics that were compared included vegetation structure (e.g., basal area, canopy height, canopy and edge closures) and composition (e.g., species diversity and richness, species importance values). Nonparametric statistics were employed for this comparison with supporting data provided by Two Way Indicator Species Analysis (TWINSPAN), a clustering technique. Detrended Correspondence Analysis (DCA), an ordination technique, was further employed to determine whether any predominant underlying environmental gradient could be detected among the quadrats based on canopy species distribution.

Results showed that sampled stands in riparian and mesic habitats were similar in productivity based on basal area, but differed significantly in their structure and composition. Stands in the mesic shoreline habitat exhibited characteristics of unmanaged broadleaf mesic forests.

Twenty-nine hardwood taxa were represented in the canopy with a predominance of oaks and hickories. Stands in the riparian shoreline habitat were compositionally similar to regional bottomland forests and were limited to 16 canopy species with a predominance of *Acer saccharinum*. An assessment of similarity in canopy species of the two habitats yielded a Coefficient of Community of 0.33. The arboreal community in the mesic habitat was also significantly richer and more diverse than the community in the riparian habitat.

TWINSPAN and DCA confirmed compositional dissimarilarity in sampled habitat stands. TWINSPAN partitioned mesic and riparian quadrats into two separate clusters. DCA segregated quadrats by habitat along an underlying environmental gradient. Analysis of this gradient indicated that it was related to subsurface lateral pool flow. Separate DCA analyses of mesic and riparian quadrats showed no predominant environmental gradient within either habitat.

Structurally, riparian stands were significantly shorter, more open in their canopy, and denser in understory and edge front than mesic stands. Riparian stands characteristically presented a dense curtain-like edge cover composed of three common understory species, *Cornus amomum, Alnus serrulata,* and *Ligustrum sinense.*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

<	less than
>	greater than
≤	equal to or less than
≥	equal to or greater than
α	significance level
°C	degrees Celsius
°F	degrees Fahrenheit
CC	Sørenson Coefficient of Community
cm	centimeter(s)
DBH	diameter at breast height
DCA	Detrended Correspondence Analysis
D-D	Domin-Dahl
E	Equitability Index
EIS	Environmental Impact Statement
FAC	facultative
FACU	facultative upland
FACW	facultative wetland
ft	foot
H′	Shannon Index of Diversity
ha	hectare(s)
IV	importance value
km	kilometer(s)
m	meter(s)

m^2	meter square
msl	mean sea level
NOAA	National Oceanic and Atmospheric Administration
OBL	obligate
PF	percent frequency
RD	relative density
RF	relative frequency
spp.	species
TRM	Tennessee River Mile
TVA	Tennessee Valley Authority
TWINSPAN	Two Way Indicator Species Analysis
UPL	upland

1.0 INTRODUCTION

1.1 Background

Since 1933 the Tennessee Valley Authority (TVA) has established 15 major reservoirs on the Tennessee River above Chattanooga, Tennessee, creating over 8,400 km of reservoir shorelines and redefining the Tennessee River basin landscape. Previously mesic habitats were flooded and adjoining upland habitats became a part of the newly formed shorelines.

On Watts Bar, the largest of these reservoirs, investigations have been conducted to determine how its construction five decades ago influenced shoreline woody plant communities that were once distant from the Tennessee River shoreline. These studies found that where shoreline slopes and scarps are conducive to subsurface lateral reservoir pool flow (incursion) in the rhizosphere, forests subsequently established that are compositionally similar to stands in unmanaged bottomland and riverine riparian habitats. Based on readings from wells installed along transects perpendicular to the reservoir, riparian woody plant species were found to predominate where estimated depth-to-summer reservoir pool incursion was less than 0.5 m (Figure 1.1, Sketch B) (Amundsen, 1994; Loy, 1994).

Frye and Quinn (1979) came to similar conclusions in a study of floodplain forest communities adjacent to the Raritan River in New Jersey. They found that in those areas where the water table was greater than 0.6 m from the surface, there was a significant change in species composition and in other such community characteristics as species richness and diversity.

Not all reservoir shorelines are predisposed to riparian conditions. Shoreline topography may minimize the influence of sublateral pool flow. On shorelines with steep slopes, the abrupt rise to drier soil conditions may limit the inland extent of shoreline having a reservoir-imposed saturated root zone. On shorelines that are severely cut back, resulting in extensive vertical scarp formations, or that are rock-defended or bluff-like, the elevated topography may place the root zone above

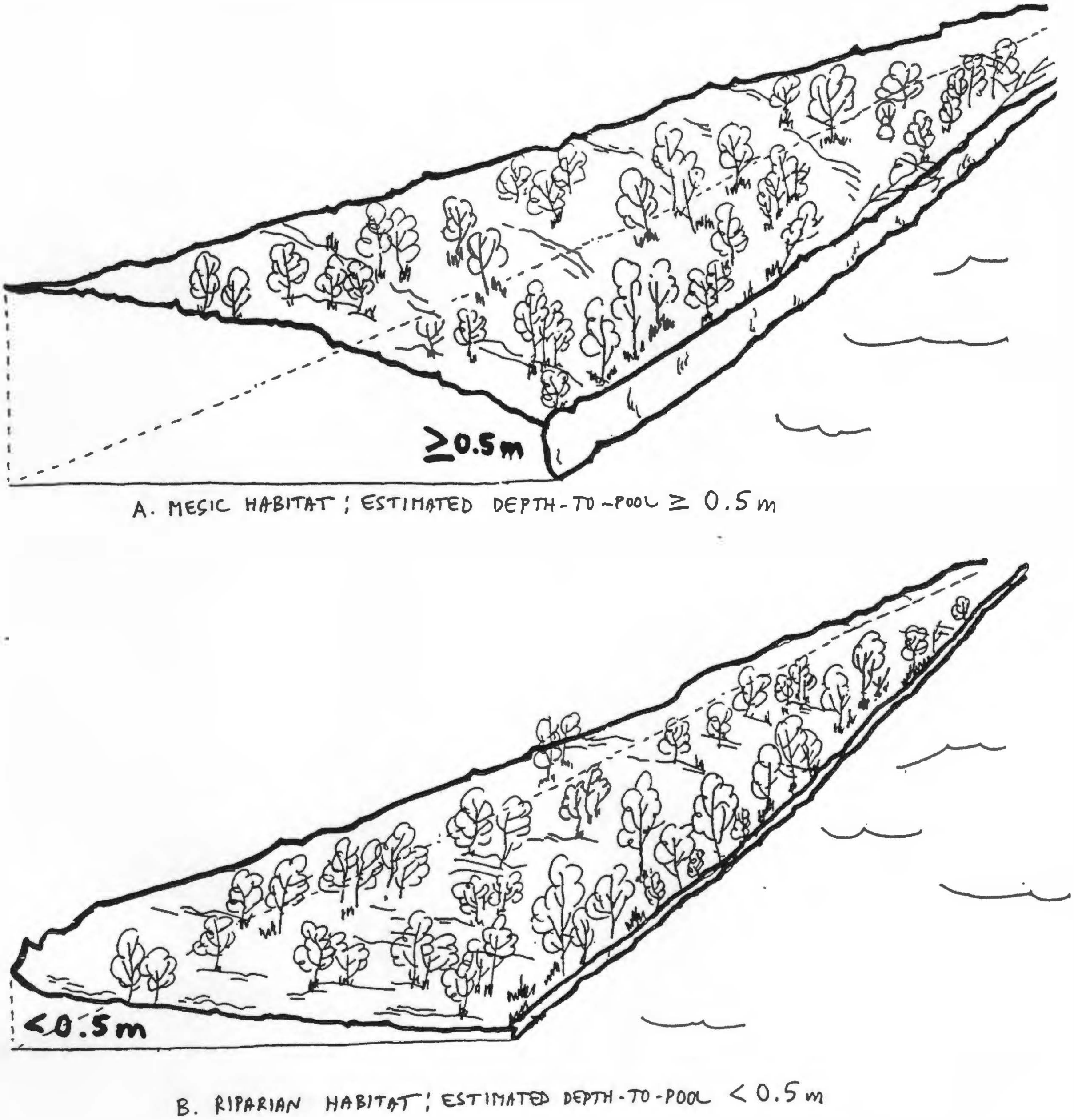


Figure 1.1 Graphic Depiction of Mesic and Riparian Habitats

and outside the influence of the sublateral pool flow.

Whether shoreline habitats are influenced by flooding or subsurface lateral pool flow or not, they are often collectively referred to as 'riparian' because they are located adjacent to a body of water. In this study, this term was only applied to hydrically influenced shorelines. A shoreline habitat was defined as *riparian* if depth-to-subsurface lateral pool flow was estimated to be less than 0.5 m to soil surface and *mesic* if estimated depth-to-subsurface lateral pool flow was greater than or equal to 0.5 m (Figure 1.1).

1.2 Purpose

The primary purpose of this study was to determine compositional and structural differences between edges of mature forest stands established in a *riparian* habitat and those established in a *mesic* habitat along Watts Bar shoreline. Forest stand edges examined were located in quadrats placed within four meters from the summer pool. Characteristics that were compared included vegetation structure (e.g., basal area, canopy height, canopy and edge closures) and composition (e.g., species diversity and richness, species importance values). Nonparametric statistics were employed for this comparison with supporting data provided by a cluster analysis. A review of the literature reveals that differences between forest stand edges located in these two contrasting habitats have not been formally measured on Watts Bar or any other reservoir.

A preliminary investigation was also conducted to determine whether any predominant underlying environmental gradient among the shoreline quadrats could be detected based on sylvic species distribution. Soil moisture, including saturation, has long been recognized as a primary environmental gradient upon which plant species populations are organized (Whittaker, 1975; Adams and Anderson, 1980; Tanner, 1986). However, with the geomorphedaphic variation in reservoir shorelines, soil moisture may be only one of many environmental gradients found along the reservoir pool. Ordination analysis was used to determine if there was a predominant gradient organizing species among quadrats and, if so, whether this gradient was related to the apparent soil saturation from subsurface inflow of the reservoir pool.

1.3 Application

As shorelines retreat due to continued erosion (Amundsen, 1994), management is required to conserve the ecological and socioeconomic functions of mesic and riparian forested shoreline habitats. These habitats defend against shoreline degradation; enhance water quality by sequestering excess nutrients, chemicals, and sediments; provide allochonthous input as a base food for the reservoir's trophic web; provide faunal habitats; and contribute aesthetic, recreational, and resource values (Lowrance et al., 1984; Gregory et al., 1991; Malanson, 1993; TVA, 1996).

TVA has recently published a draft Environmental Impact Statement (EIS) for recommending further residential development alternatives along shorelines of the Tennessee River mainstem and tributary reservoirs. TVA's preferred management alternative includes developing shoreline plans based on resource inventories. From this analysis, TVA will identify shoreline segments where human disturbance will not be permitted and other segments where 100 foot wide vegetative buffer strips or "shoreline management zones" will be established. Currently, 22% of the shoreline has been developed (TVA, 1996).

To optimally ensure that such management plans conserve the unique contributions of these forested shorelines, it is necessary to know the structure and composition of the forest stands and to understand how these communities are related to their physical environment. This thesis provides a basis for this knowledge and understanding by providing preliminary data on riparian and mesic forested habitats along Watts Bar Reservoir shoreline.

2.0 REVIEW OF SELECTED LITERATURE

2.1 Introduction

This chapter reviews selected literature, including historical documents that were used to interpret study findings. Section 2.2 describes the composition of mesic forests located in proximity to Watts Bar shoreline. Section 2.3 provides a historical account of how lands adjacent to the reservoir pool were used prior to impoundment and how TVA modified the impoundment area in preparation for flooding. It also provides insight into current shoreline conditions, including vegetation patterns and bank morphology, discussed in Section 5.0.

Section 2.4 describes TVA reservoir riparian habitats, including their engineered hydrologic regime and woody shoreline vegetation. Section 2.5 describes individualistic and community adaptations of woody plants to hydric conditions and hydric tolerance lists. Finally, Section 2.6 reviews forest edge studies that have found certain distinguishing structural and compositional characteristics ("edge effects") that may be comparable to those found in forest stands along Watts Bar shoreline.

2.2 Watts Bar Mesic Forest Stands: A Regional Perspective

Watts Bar Reservoir is located in the Ridge and Valley Physiographic Province in East Tennessee. Braun (1950) placed this area in the Oak-Chestnut Forest Region of the Deciduous Forest Formation of eastern North American. Kuchler (1964) described this area as part of the Appalachian Oak Forests and Bailey (1995) described it as part of the Broadleaf Mesic Forests.

A 1941 TVA study recognized four forest types in the Ridge and Valley Physiographic Province: Yellow-Pine-Hardwood; Upland Hardwood, characterized by oak and hickory taxa; Oak-Chestnut; and Blackjack Oak-Hardwoods. The Upland Hardwood type more commonly occupied moist sites, while the Yellow-Pine, Oak-Chestnut, and Blackjack Oak-hardwoods occupied drier sites (TVA, 1941 as cited in Martin, 1971). A more recent TVA publication described this area as containing predominantly mixed hardwoods with no more than 25% pine (TVA, 1984).

In a study of forest communities in the central portion of the Ridge and Valley Physiographic Province, Martin (1971) recognized the diversity of this region by establishing four major conceptual complexes: the White Oak, Chestnut Oak, Tulip Poplar, and Mixed Mesophytic. He also recognized a less well-represented bottomland hardwood community. Martin's study encompassed forest stands located in Loudon and Roane Counties, where 68% of Watts Bar Reservoir is located. Within these stands, he identified forest communities under each of the four complexes and a bottomland community as shown in Table 2.1. With the exception of the Mixed Mesophytic Complex that contained no predominant species, Martin identified communities based on codominant species. Table 2.1 also provides four species within each community with the highest ranked importance values after the codominant species to further indicate the types of species found in this region.

2.3 Preimpoundment Land Use and Impoundment Preparation

An account of land use adjacent to Watts Bar Reservoir prior to impoundment is provided in a 1938 study by G.T. Olsen. A land use planner, Olsen was charged by TVA with estimating the "character of the land to be flooded and the land that might be included in a taking line" for the impoundment. The study design included taking 18 square mile samples five miles apart on alternate sides of the Tennessee River and its main tributaries (Olsen, 1938).

Olsen determined that the use of the land to be flooded by the closure of Watts Bar Dam was markedly different from that of the land adjacent to the then proposed reservoir pool line. Of the approximately 30,900 acres of land designated for flooding, he estimated that 90% was used for agriculture, less than one percent was abandoned, and only 8.6% was forested. An assessment of land quality in relation to crop production rated over 60% of this land as "high quality."

In contrast, from an analysis of a strip of land located within about ½ mile from the proposed reservoir pool (estimated at that time to be at 745 ft msl), 44% was estimated to be

Table 2.1 Forest Stand Communities Identified by Martin (1971) in Roane and Loudon Counties

Communities within Complexes	Commonly Associated Species
Chestnut Oak Complex	
Chestnut Oak	*Pinus echinata; Nyssa sylvatica; Carya ovata; Carya glabra*
Chestnut Oak-Virginia Pine	*Liriodendrum tulipifera; Carya ovata; Carya tomentosa; Robinia pseudoacacia*
Chestnut Oak-Black Oak	*Quercus stellata; Pinus echinata; Quercus alba; Carya tomentosa*
Chestnut Oak-Tulip Poplar	*Carya glabra; Quercus alba; Nyssa sylvatica; Quercus vellutina*
Mixed Mesophytic Complex (highly variable)	*Acer saccharum; Carya glabra; Quercus prinus; Juglans nigra*
Tulip Poplar Complex	
Tulip Poplar-White Oak	*Cornus florida; Quercus falcata; Quercus rubra; Acer saccharum*
White Oak Complex	
White Oak	*Quercus velutina; Oxydendrum arboreum; Quercus falcata; Quercus prinus*
White Oak-Chestnut Oak	*Liriodendron tulipifera; Quercus coccinea; Carya glabra; Quercus rubra*
White Oak-Shortleaf Pine	*Carya tomentosa; Quercus velutina; Quercus virginiana; Oxydendrum arboreum*
White Oak-Scarlet Oak	*Quercus falcata; Quercus velutina; Carya tomentosa; Carya glabra*
White Oak-Tulip Poplar	*Carya ovalis; Carya tomentosa; Quercus rubra; Quercus coccinea*
White Oak-Black Oak	*Carya glabra; Carya tomentosa; Liriodendrum tulipifera; Pinus echinata*
White Oak-Shagbark Hickory	*Carya glabra; Pinus virginiana; Quercus rubra; Quercus muhlenbergii*
White Oak-Sweet Pignut Hickory	*Quercus rubra; Quercus velutina; Nyssa sylvatica; Oxydendrum arboreum*
White Oak-Virginia Pine	*Quercus velutina; Quercus stellata; Quercus falcata; Liriodendrum tulipifera*
Bottomland (Green Ash-Sycamore)	*Salix nigra; Ulmus americana; Quercus phellos; Quercus alba*

forested, 50% agricultural, 5% abandoned, and 1% streams. This land was assessed as "generally intermediate in quality between the good bottomlands and the poorer uplands..." (Olsen, 1938). In a technical report describing the Watts Bar Project, TVA stated that of the approximately 21,400 acres acquired above the 745 ft msl level (the maximum operating level of the reservoir), about 47% was forested (TVA, 1949). This estimate closely corresponds to Olsen's estimate (1938).

Land use adjacent to the reservoir pool was also analyzed in relation to the slope of the land (Figure 2.1, Chart 1). Approximately 50% of the land was classified as having a gentle slope (less than 20%), 12% was of moderate slope (between 20 to 40%) and 8% had a steep slope (over 40%). The percentage of land covered in forest increased as slope increased (Olsen, 1938).

Olsen also estimated the extent of erosion of the land bordering the reservoir (Figure 2.1, Chart 2). Sixty-six percent of the erosion occurred on lands with a gradient less than 20% and approximately 80% of the erosion occurred on crop and grazing lands. From these findings, coupled with the finding that about 80% of crop and grazing land was on gentle slopes (Figure 2.1, Chart 3), Olsen concluded that erosion in this area was influenced more by farming technique than by slope and that application of better farming practices would be equally as effective in controlling shoreline erosion as TVA acquiring and managing a broad strip of land (Olsen, 1938).

In preparation for Watts Bar Dam closure and subsequent flooding, TVA employed two types of vegetation clearance from reservoir land: (1) regular and bank clearing and (2) marginal clearing. Regular and bank clearing operations consisted of complete removal of timber and brush from the reservoir land up to the normal pool level. Approximately 2,956 ha (7,305 acres) of woodland were removed (TVA, 1949), 19% of the current pool area.

Marginal clearing involved removing "all underbrush, dead or undesirable timber and other debris" for a horizontal distance of 4.6 m (15 ft) or .46 m (1.5 ft) vertically above the normal pool contour, whichever was reached first. Aboveground vegetation was completely removed in two

Chart 1: Relationship of Land Use and Land Slope[2]

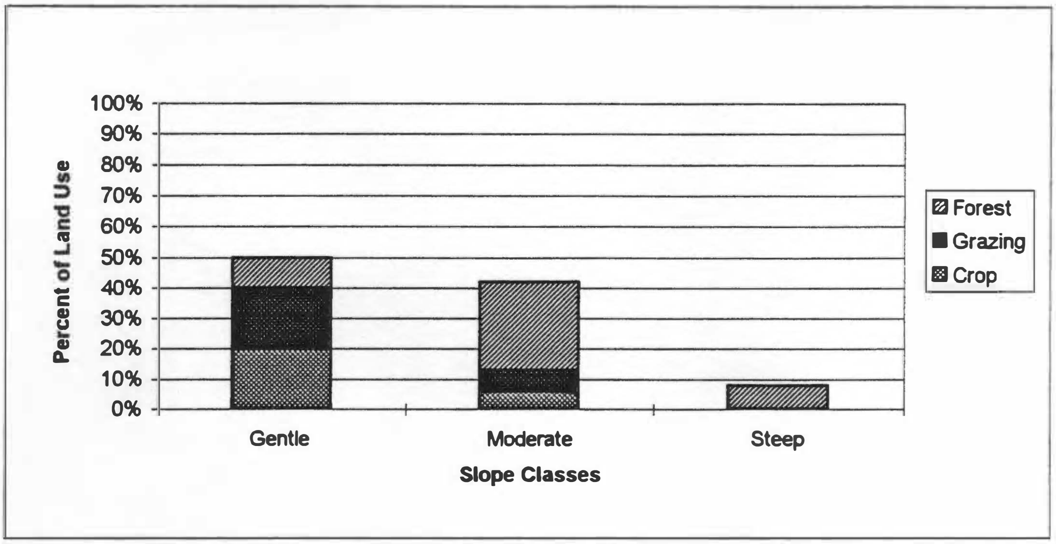


Chart 2: Relationship of Soil Erosion and Land Slope[2]

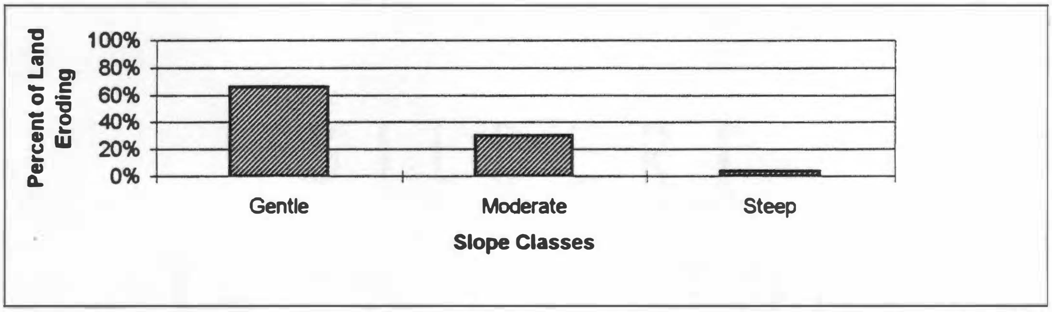
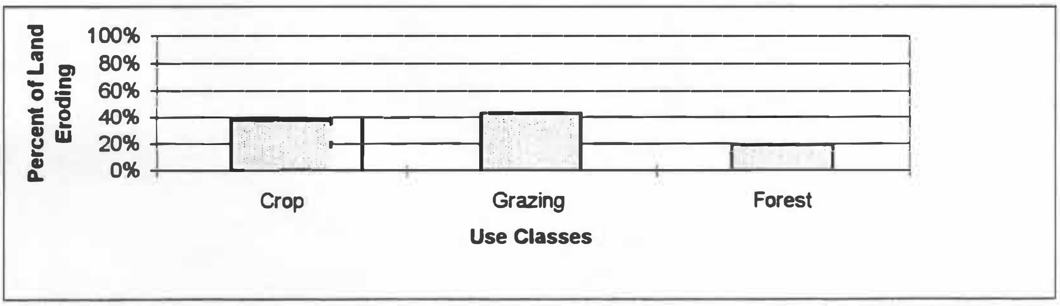


Chart 3: Relationship of Soil Erosion and Land Use



[1]Based on 1/2 mile strip from 745 ft msl

[2]Gentle Slope = less than 20%; Moderate Slope = 20% to 40%; Steep Slope = over 40%

Source: Olsen (1938)

Figure 2.1 1938 Analysis of the Relationships Among Land Use, Soil Erosion and Slope on Lands Bordering the Contemporary Watts Bar Summer Pool[1] areas. At the upper end of shoreline indentations where debris was likely to collect, clearing was carried out for a distance of 7.6 m (25 ft) horizontally beyond the normal pool contour to provide space for piling and burning debris. On banks where erosion from wave action was deemed likely to occur, clearing was extended 3.05 to 6.10 m (10 to 20 ft) to reduce debris flotage. Removal was done mechanically and by hand labor. For purposes of vegetation clearance, the normal pool level was designated as 225.9 m (741 ft) msl at the dam with 0.15 m (0.5 ft) adjustments upstream to 226.3 m (742.5 ft) msl at the head of the reservoir (TVA, 1949).

2.4 TVA Reservoirs' Riparian Habitats

2.4.1 Hydrologic Regime

The supply of water to shoreline habitats by impounded rivers is comparable in many respects to that in unmanaged riverine systems. In both, shoreline habitats receive water from surface flow, groundwater and precipitation. Water detention and water loss in both habitats is regulated by the combined effects of soils, geomorphic features and vegetation. For example, the U.S. Army Corps of Engineers, in its hydrogeomorphic assessment of riverine wetlands, considers factors affecting potential water detention. These factors, including microtopographic complexity, density and size of woody stems and extent of woody debris, can also be applied to reservoir riparian areas. Variables in the Corps' evaluation of subsurface water flow include the presence or absence of underlying horizons or strata that may restrict flow due to lower permeability (Brinson et al., 1995).

Although sources of, and factors affecting, water supply to shoreline habitats in managed and unmanaged riverine systems are similar in many respects, they also differ in one obvious way. Water levels in reservoirs are engineered in accordance with a management operating program. Whereas in riverine wetlands the dominant water source is overbank flow from the channel (Brinson et al., 1995), one of TVA's operating program goals for its reservoirs is to minimize flooding. This is achieved by lowering reservoir levels to increase the storage volume available for potential flood waters. Thus, reservoir riparian shoreline habitats may actually receive less annual surface water supply than unmanaged riverine systems.

The TVA operating plan for its East Tennessee reservoirs specifies a normal pool from spring to late summer, with a drawdown pool only during the winter months (TVA, 1990). This hydrologic regime is opposite of the winter high-summer low water levels common to the wild rivers of this region. The result is that the mainstream reservoir riparian shorelines are exposed to at least a partial root zone saturation throughout their entire growing season (April through October).

2.4.2 Vegetation Studies

Studies conducted on the woody vegetation along impoundment shorelines of the Tennessee River have been limited. In 1946, Hall, Penfold and Hess examined the phenology of marginal vegetation on these reservoirs in relation to the control of malaria. In 1955, Hall and Smith investigated the general effects of flooding on woody plants in a Kentucky Reservoir on the Tennessee River. The latter study was, again, conducted in relation to the control of anophelism.

In 1994, Amundsen reported on forest stands along Watts Bar Reservoir shoreline. Amundsen's transects were located normal to the shoreline on slopes conducive to subsurface lateral pool flow in the rhizosphere at normal pool level. Results of his study demonstrated a floristic similarity between Watts Bar shoreline forest stands and other southern bottomland forests. He determined mean basal area to be 19.6 m^2/h, less than two-thirds of the mean basal area of regional riverine stands. Litter accumulation, however, was approximately 12% higher than previously reported for mesic forest stands in East Tennessee. Canopy closure ranged from 60 to 90%, with a median of 80%.

2.5 Individualistic and Community Adaptations to Hydric Conditions

This section discusses factors that determine the adaptability of woody plant species under varying hydric conditions and describes noted physiological and morphological adaptive mechanisms. It then reviews studies that have examined community responses to a range of hydric conditions. This is followed by a discussion of classification systems used to identify plant hydric tolerances.

2.5.1 Plant Adaptations

The ability of a woody plant to adapt and survive in a newly wet environment is determined by its apparent genetic capability and the hydroperiod profile it must endure. The former includes its phenotypic ability to adapt its life history strategy and/or physiological and morphological features to hydric situations. The latter includes time of year, duration, depth, and frequency in relation to a plant's life history strategy and developmental stage.

Physiological and morphological adaptations of trees to flooding have been summarized by Teskey and Hinckley (1977a). Based on work largely conducted by Hosner and Boyce (1962) and Hook and Brown (1973), these authors primarily attributed a species' water tolerance to its ability to adapt its root structure and function to counter an anaerobic environment surrounding the root system. They assumed that despite any number of aerial adaptations, plants cannot long survive without functional roots. Others maintained that life history strategies, especially timing and modes of seedling dispersal, germination requirements, and seedling growth rates may be as important to species survival as physiological and structural mechanisms of flood tolerance (Sigafoos, 1961 as cited in Franz and Bazzaz, 1977).

Plant adaptations were comprehensively examined by Hook (1984) and Kozlowski (1984). Morphological adaptations have been shown to include adventitous roots, increased length of lateral roots, shallow root systems, lignification and suberization of roots, hypertrophied lenticels, and formation of aerenchyma (i.e., tissue composed of cells separated by gas-filled spaces) (Teskey and Hinckley, 1977a; Tiner, 1991). Examples of physiological adaptations include transport of oxygen to roots from aerial parts of plant, acceleration of anaerobic respiration in roots, and oxidation by roots of their immediate rhizosphere.

Species less tolerant to saturated conditions have been shown to have decreased rates of photosynthesis, transpiration and nutrient uptake that eventually lead to plant death under extended inundated conditions (Teskey and Hinckley, 1977a; Malanson, 1993 citing numerous studies). Certain species also appear to have wide ecological amplitudes that allow them to thrive in both riparian and mesic habitats. *Acer rubrum* is a prime example: "In swamps, it develops numerous shallow lateral roots to help avoid anaerobic stress, whereas in dry uplands a deep taproot is formed" (Kramer, 1949 as cited in Tiner, 1991).

2.5.2 Community Adaptations

Numerous studies have examined influences of soil water regimes on plant communities, involving both direct (e.g., depth-to-water table, soil moisture) and indirect (e.g., elevation, soil texture) hydric measurements. These studies also encompassed a range of hydrically influenced landscapes. Boedeltje and Bakker (1980) analyzed effects of differing water table levels (in addition to other environmental variables) on herbaceous plant communities in a small valley in the Netherlands. Results from their application of a Braun-Blanquet approach indicated that where the water table was less than 0.4 m to the surface, hydrology appeared to be the principal factor determining the composition of these plant communities.

Frye and Quinn (1979) examined compositional and structural differences in forests on a floodplain of the Raritan River, New Jersey. Transects were taken perpendicular to the river from "low areas" (< 3.5 m msl) where the water table was generally less than 0.6 m from the surface to "high areas" (> 0.5 m msl). Comparisons of the woody species in these two areas demonstrated consistent vegetational differences including greater species richness, species diversity, equitability, basal areas of trees, and total shrub cover in the elevated area. The authors "more closely associated" these vegetational differences with the depth-to-water table than any other variable.

Studies examining forest characteristics along moisture gradients have resulted in similar findings. Adams and Anderson (1980), using Polar and Gaussian ordination, demonstrated a gradual shift in species composition on a soil moisture gradient in 37 forest sites in Illinois. This gradient was indirectly measured by a complex of environmental factors (e.g., water holding capacity of soil, vegetation slope position). Tree diversity was found to be maximal on mesic sites and to decrease toward the extreme ends of the gradient. Bell (1980) examined vegetation changes along a flood-frequency gradient perpendicular to a streamside forest in Illinois. Results demonstrated that species richness, diversity and evenness increased from minima at the streambank (i.e., the most severely flooded habitats) to maxima in habitats where flooding was infrequent. Species dominance was strongest at the extremes of the gradient. Other researchers who demonstrated a significant relationship between floodplain forest composition and soil hydrology include Franz and Bazzaz in Illinois (1977), Wheeler and Kapp in Michigan (1978), Tanner in Lousiana (1986), and Hunneke in New York (1982).

Simon and Hupp (1987) analyzed riparian vegetation in relation to the morphologic changes of stream banks following dredging and straightening of a stream channel. Although this study did not directly examine hydrologic influences on plant communities, it did demonstrate that changes in fluvial processes can affect plant community composition. Using Detrended Correspondence Analysis (DCA), these authors showed a change in plant community composition in each stage of a six-stage model of stream channel adjustment.

2.5.3 Hydric Tolerance Classification Systems

A number of classification systems have been developed to identify how well certain plants tolerate varying hydric conditions (Hall et al., 1946; Teskey and Hinckley, 1977b; Reed, 1988). The criteria that form the bases for these classifications vary and species included in the lists are generally regionally or subregionally specific. For example, the Fish and Wildlife Service developed four tolerance lists for tree species in the Eastern Deciduous Forest Region. Tolerance levels were based on the length of flooding trees can endure during the growing season(s). This was evaluated, in part, by the species' abilities to adapt their root systems under inundated conditions (Teskey and Hinckley, 1977b).

The Fish and Wildlife Service also developed the National List of Plant Species that Occur in Wetlands ("National List") (Reed, 1988). This list uses five indicator assignments based on differences in expected frequency of occurrence of a plant in wetlands: obligate wetland (OBL); facultative wetland (FACW); facultative (FAC); facultative upland (FACU); and upland (UPL). Within this list, a species is often given more than one indicator assignment. The species may also be assigned a regional indicator, specifying a certain region where phenotypes of that species appear to be more adaptable to hydric conditions.

Tiner (1991), in a discussion of the use of plant species as wetland indicators, recommends several caveats when using these lists. First, certain plant species exhibit broad ecological amplitudes in their adaptations to hydric condition and may be appropriately classified under more than one hydric tolerance category. The National List attempts to address this issue by including plants under more than one category. Second, the success of a typically mesic or xeric sapling in a wet environment may be the result of an individualistic adaptation (e.g., favorable conditions during its early stage) which may not represent the typical habitat for that species. Third, the plant may be part of an "ecotype" (i.e., subspecies) that has morphologically or physiologically adapted to a habitat that, again, is distinctive from that known for its species. Tiner cautioned that when using these lists, a plant's response to inundation may be quite different from its response to soil saturation. For example, species tolerance lists developed by Teskey and Hinckley (1977b) use criteria to differentiate species based primarily on their response under flooded conditions. Lists such as these do not fully apply to all riparian conditions including those found along Watts Bar shorelines.

Species tolerance lists for woody plants found on Watts Bar shorelines have been compiled by Loy (1994) who employed data from Hall et al. (1946), Mann and Bierner (1975) and USACE (1986) and technical guidance from DeSelm (1985). These lists are provided in Table 2.2 and include species she observed in the shoreline riparian habitat (and to a lesser extent in the riparian-to-mesic transitional habitat). To permit comparison of Loy's species tolerance lists and the National Wetland List, Table 2.2 also contains the National Wetland Indicator assignments (Reed, 1988).

2.6 Edge Effects: Relevance to Reservoir Shoreline Forest Stands

"Edge effects" have traditionally been examined at the boundary where forests have been cut and where there is an abrupt change between a clearing and the remaining forest. However, results from these studies may also serve, at least in part, to interpret findings from the analysis of reservoir shoreline forest stands. In one sense, shoreline stands can be viewed as having at least one edge (or more if located on a peninsula) that is perpetually "maintained" by truncation by the reservoir summer pool. Ranney (1978) described how forest edge structure is dependent on its maintenance and identified several ways edges are maintained. From his descriptions, the reservoir forest edge may be defined as a "cantilevered edge," one that is maintained at the base of the edge trees.

The structure of forest edge communities has been found to differ from that in the forest interior. Studies have demonstrated that the basal area of tree and/or poles in the forest edge is significantly greater than in the forest interior (Wales, 1972; Ranney, 1978; Williams-Linera, 1990). Ranney found that 40-70 year age class forest stand edges with a cantilevered structure had an average basal area of 43.8 m^2/ha, while those in the over 70 age class had a basal area of 67.4 m^2/ha. In contrast, interior forest basal area for the former and latter age classes were 32.2 and 34.5 m^2/ha, respectively.

Table 2.2 Hydric Tolerance Lists of Woody Species Found on Watts Bar Shoreline[1] and Their Federal Wetland Indicator Designations[2]

Most Tolerant[1]	*Moderately Tolerant*[a]	*Least Tolerant*[1]
Acer negundo: FAC,FACW; FACW	*Acer saccharinum*: FAC,FACW; FACW	*Acer nigrum*: not listed
Acer rubrum: FAC	*Arailia spinosa*: FAC,FACW-; FAC	*Carya glabra*: FACU-,FACU; FACU
Acer saccharinum: FAC,FACW; FACW	*Carpinus caroliniana*: FAC; FAC	*Carya tomentosa*: not listed
Alnus serrulata: FACW+,OBL	*Carya ovata*: FACU-,FACU+; FACU	*Cercis canadensis*: UPL,FACU; FACU
Amorpha fruticosa: FAC,OBL	*Carya tomentosa*: not listed	*Hamamelis virginiana*: FACU,FACW; FACU
Betula nigra: FACW, OBL; FACW	*Cercis canadensis*: UPL,FACU; FACU	*Juniperus virginiana:* FACU-,FACU; FACU-
Carpinus caroliniana: FAC; FAC	*Diospyros virginiana*: FACU,FAC; FAC	*Nyssa sylvatica*: FAC; FAC
Celtis occidentalis: FACU, FAC; FACU	*Fagus grandifolia*: FACU; FACU	*Oxydendron arboreum*: FACU(tenative assignment); no indicator
Cephalanthus occidentalis: OBL; OBL	*Fraxinus americana*: FACU; FACU	*Pinus virginiana*: not listed
Cornus amomum: FACW,FACW+; FACW+	*Gleditsia triacanthus*: FACU,FAC; FAC-	*Quercus marilandica*: not listed
Cornus foemina: FAC,FACW: FACW	*Ilex opaca*: FACU,FAC-; FAC-	*Quercus prinus*: not listed
Fraxinus lanceolata (pennsylvanica): FACW	*Juniperus virgininiana*: FACU-,FACU; FACU-	*Quercus stellata*: not listed
Gleditsia triacanthos: FACU,FAC; FAC-	*Liriodendron tulipfera*: FACU, FAC; FAC	*Quercus velutina*: not listed
Ilex opaca: FACU,FAC-; FAC-	*Ostrya virginiana*: FACU,FAC-; FAC-	*Rhamnus caroliniana*: FACU-,FAC; FACU
Liquidambar styraciflua: FAC,FACW; FAC+	*Oxydendrum arboreum*: FACU (tenative assignment; not identified)	*Robinia pseudo-acacia:* UPL,FAC; UPL
Morus rubra: FACU, FAC; FAC	*Pinus virginiana*: not listed	*Sassafras albidum:* FACU-,FACU; FACU
Ostrya virginiana: FACU,FAC-; FAC-	*Prunus serotina*: FACU; FACU	
Platanus occidentalis: FAC,FACW; FACW-	*Quercus marilandica*: not listed	
Quercus bicolor: FACW+,OBL; FACW+	*Quercus rubra*: FACU-,FACU+; FACU	
Salix nigra: UPL,OBL; OBL	*Quercus stellata*: not listed	
Smilax, sp.: (range for genus): OBL-FACU; FACW-FACU	*Robina pseudo-acacia*: UPL,FAC; UPL	
Ulmus americana: FAC,FACW; FACW	*Sassafras albidum*: FACU-,FACU; FACU	
Ulmus rubra: FAC; FAC	*Tilia, spp.*: (for *T. americana):* FACU; FACU	
	Ulmus alata: FAC,FACW; FACW	

[1]Species lists from Loy (1994). Criteria used by Loy to compile lists were: (1) Only species she observed along Watts Bar Reservoir shoreline were included; (2) If a species was listed by two different authors as cited in Loy (USACE, 1986; DeSelm, 1985; Hall et al., 1946; Mann and Biemer, 1975) in adjacent categories, the species was included in both categories; (3) If a species was listed by two different authors in opposite categories (most tolerant and least tolerant), the species was considered "moderately tolerant."

Table 2.2 Hydric Tolerance Lists of Woody Species Found on Watts Bar Shoreline[1] and Their Federal Wetland Indicator Designations (continued)[2]

[2]Wetland indicator designations from Reed (1988). The first designation identified after the species' scientific name is its "national indicator" status (e.g., an indicator designation of "FAC, FACW" means that 34-99% of the sample plots containing *Acer negundo* randomly selected across the nation would be wetland). The second designation (e.g., "FACW") is the species "regional indicator" status. "Plus" after the designation (e.g., FAC+) indicates that the species occurs in the higher portion of the range in the wetlands (e.g., 51-66% of the time) whereas "minus" (e.g., FAC-) indicates the lower portion of the range (e.g, 49-34%).

Wetland Indicator Designation	Estimated probability of occurrence in wetlands	Estimated probability of occurrence in nonwetlands
Obligate wetland (OBL)	>99%	< 1%
Facultative wetland (FACW)	67-99%	1-33%
Facultative (FAC)	34-66%	34-66%
Facultative upland (FACU)	1-33%	67-99%
Upland (UPL)	< 1%	> 99%

Growth form of forest edge trees has also been observed to be distinctly different from that of the forest interior. Trees at the edge often have minimal branching on the interior (forest grown) side of the bole and more frequent and larger branching on the side of the clearing accompanied by boles that lean toward the clearing (Ranney, 1978). Wales (1972) noted that the lateral outward projecting branches of the canopy and subcanopy species "intermingling" with woody vines in the shrub zone, gave a thicket-like appearance to the edge.

The composition of a forest's edge also may significantly differ from that of its interior. Wales (1972) found that species characterized by shade intolerance, good vegetative reproduction, or both, were prevalent at the edges. These included, but were not limited to, *Fraxinus americana, Prunus serotina, Sassafras albidum*, and *Viburnum prunifolium.* Ranney (1978) also found tree distribution to be directly related to the proximity of edges. Importance values of edge-oriented species (e.g., *Fraxinus* spp.) peaked within ten meters from the edge. Matlack (1994), in an examination of forest herbs, shrubs, and tree seedlings in forest edges, also showed an edge-related pattern in overall species composition with "edge-oriented species" generally being clustered less than or equal to five meters from the edge.

Forest edge structure and composition have, in part, been attributed to alterations in abiotic conditions (Wales, 1972; Matlack, 1993). Matlack (1993) demonstrated significant edge effects in light, temperature, and humidity. Variables dependent on direct beam radiation loads (e.g., vapor pressure deficit, temperature) showed strong edge-oriented gradients in edges facing all cardinal directions except north. However, shoreline edge effects due to aspect may be attenuated by the reduced air temperature amplitude and increased humidity found in areas adjacent to bodies of water (Hutchinson, 1975).

3.0 STUDY SITE

3.1 History

TVA was established as a federally-owned corporation by Congressional passage of the TVA Act in 1933. Congress authorized TVA to create a navigation channel from the headwaters of the Tennessee River at Knoxville, Tennessee to its mouth at Paducah, Kentucky; to provide for the control of flooding; and to generate power. Other subsidiary purposes authorized by Congress included reforestation, the proper use of marginal land, and agricultural and industrial development (TVA, 1949).

The Watts Bar Dam project was one of nine multipurpose projects included in TVA's 1936 plan presented to Congress for the unified development of the Tennessee River. Congress appropriated funds for the Watts Bar project in March of 1939. In July of that same year, the project was initiated (TVA, 1949). With the outbreak of World War II and the subsequent national wartime emergency, the Watts Bar project was declared vital to defense. Construction was completed ahead of schedule. Reservoir filling began January 1, 1942 and the lock was opened to navigation on February 16, 1942 (TVA, 1949).

3.2 Location and Dimensions

Watts Bar Reservoir is located in Roane, Rhea, Meigs, and Loudon Counties and has an approximate area distribution by county of 60, 20, 12, and 8%, respectively. Watts Bar Dam is located at Tennessee River mile (TRM) 529.9. The reservoir has a sail line of approximately 180 km that extends approximately 116 km to Fort Loudon Dam and 40 km up the Clinch River to the Melton Hill Dam (Loy, 1994). The impoundment also creates slack water channels suitable for navigation for about 24 km up the Emory and Little Emory Rivers from its confluence with the Tennessee River (TVA, 1949; Loy, 1994). The reservoir covers approximately 15,783 ha, which is approximately four times the area of the original river bed (4186 ha). At summer pool, the total length of the Watts Bar Reservoir shoreline is approximately 1241 km (Amundsen, 1994).

3.3 Geomorphology

The Watts Bar impoundment area is located in the midwestern portion of the Ridge and Valley Physiographic Province of Tennessee. It is bordered on the southeast by the Blue Ridge Province and on the northwest by the escarpment of the Cumberland Plateau. The reservoir is underlain by limestones, shales, and sandstones with calcareous rocks predominating (TVA, 1946). The reservoir's parent river had an average low-water slope of 0.17 m/km (0.88 ft/mi). A broad floodplain at 220 m (722 ft) msl was located in what is now the southern end of the reservoir (TVA, 1949).

The morphometry of Watts Bar Reservoir is primarily determined by its parent river channel and upland physical features. In the lower reaches of the reservoir, for example, the preimpoundment floodplain determined its breadth. In addition, the impoundment configuration was designed to accomodate navigational, flood prevention, and economic requirements. For example, the cost of dredging for navigation had to be weighed against the minimum pool elevation requirements for flood control (TVA, 1949). Excavation to reduce the length of the sail line (e.g., two main channel cutoffs, Half Moon and Thief Neck, made across peninsulas reduce the sail line by 10.06 km and to improve navigational safety (e.g., natural river bed obstructions were removed) (TVA, 1949).

The average slope of the reservoir shoreline is 9% and has been calculated using elevational and areal differences between the summer, winter, and flood pool levels (Amundsen, 1994). Shoreline configuration includes extensive bluffs and steep banks (e.g., greater than 50%), particularly in the middle reach and, to a lesser extent, in the upper reach of the reservoir.

3.4 Hydrology

The flow of the Tennessee River through Watts Bar Reservoir is generally southwesterly, roughly following the escarpment of the Cumberland Plateau. Above Watts Bar Dam, the drainage area of the Tennessee River is approximately 44,833 km^2 (17,310 mi^2), with the Clinch and Little Tennessee Rivers comprising 25 and 15% of this area, respectively (TVA, 1949).

TVA currently maintains Watts Bar pool levels at two principal elevations (Figure 3.1). From spring to late summer, the pool elevation is maintained approximately at 225.9 m (741 ft) msl. During this period, the pool is periodically fluctuated 0.3 m (1 ft) to control mosquito larval hatching. During the winter months, the level is drawn down to a minimum of 224 m (735 ft).

Appendix A, which contains weekly averages of the Watts Bar Reservoir pool levels provided by TVA for 1991 through 1995, shows pool levels rarely above the 225.9 m (741 ft) msl level. This implies equally infrequent soil saturation and flooding in the Watts Bar riparian habitat. However, because water levels were recorded as weekly averages, they did not encompass daily water level fluctuations. Daily water level data collected at TRM 580 since 1986 indicate that water levels above 225.9 m (741 ft) msl level may be more common than indicated by these weekly averages. For example, over a five month period during the growing season of 1991, 25% of the weekend water level readings were above the 225.9 m level (personal communication with Amundsen, September 1996).

3.5 Soils

The Watts Bar shoreline is primarily formed from the previously mesic slopes of the Tennessee River Valley (Amundsen, 1994). Most of the soils in the Ridge and Valley Province have formed from "residuum derived from the Paleozoic strata or from colluvium or alluvium derived from these strata deposited in later periods of geologic time" (Martin, 1971).

The Fullerton soil series was identified by Martin (1971) and Springer and Elder (1980) being predominant in this region. This series consists of deep, well-drained soils developing on broad, rounded hills and ridges. These soils are strongly acidic and not very fertile. Horizon A is silt

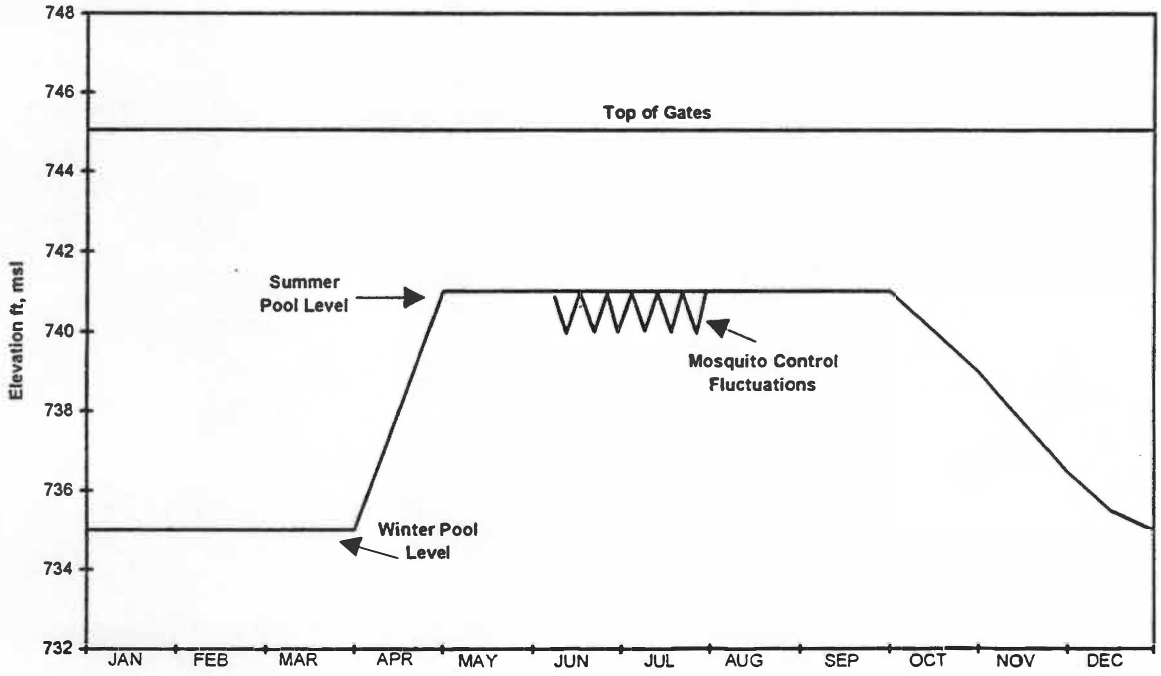


Figure 3.1 Watts Bar Annual Operating Guide

Source: Adapted from Amundsen, C. C. 1994. Reservoir riparian zone characteristics in the upper Tennessee River Valley. *Water, Air and Soil Pollution* 77:469-493.

loam or cherty silt loam and B is cherty clay. Soil cores taken by a University of Tennessee soil science student along Watts Bar shoreline in proximity to this thesis' sample areas indicate that surface soils are derived from alluvium and colluvium. Such soils showed poor A and B horizon development and occasional clay lenses (personal communication with Amundsen, July 1996).

3.6 Erosion

Erosion has been acknowledged by TVA as a problem along certain TVA reservoir shorelines and has been identified by members of the public as a primary shoreline concern (TVA, 1996). Preliminary erosion studies conducted by TVA on representative portions along Watts Bar Reservoir indicate that 91.4% of the shoreline is within acceptable erosion rate limits (i.e., no stabilization required), 5.2% is moderately eroded (i.e., bank vertical height less than 2 ft, slope less than 20%, limited vegetative cover), 1.2% is severely eroded (bank vertical height 2-6 ft, slope greater than 20%, limited vegetation cover), 2% is critically eroded (bank height 6-10 ft, limited to no vegetation cover), and 0.2% is covered by an impermeable surface (e.g., pavement) (TVA, 1996).

On the basis of long-term reconnaissance of Watts Bar Reservoir (i.e., 20 years), Amundsen contends that results from TVA's preliminary investigation do not reflect the extent and severity of erosion on Watts Bar channel frontage (personal communication with Amundsen, August 1996). For example, he has estimated that erosion is occurring up to 2 m/year in certain segments of Watts Bar shoreline and suggests that a primary contributor to erosion is waves generated by recreational boats (Amundsen, 1994).

3.7 Meteorology

The climate of the Watts Bar Reservoir region is humid mesothermal, with little or no water deficiency during any season. It is markedly influenced by its location between two mountain ranges, Cumberland Plateau to the northwest and the Unaka Mountain Range to the southeast. The Cumberland Mountains to the northeast serve to (1) retard and weaken the force of cold winter air from the northern high pressure systems, (2) reduce the penetration of hot summer winds from the plains west of the mountains, and (3) lift the warm, moist air flowing northward from the Gulf of Mexico, resulting in an increase in the frequency of summer afternoon thunderstorms (NOAA, 1993).

Records from the Lenoir City meteorological station located in Loudon County (35 ° 48' N, 84 °, 15' W) show an annual average temperature of 15.9 °C (60.6 °F) (averaged during the period from 1961 to 1990). June is generally the warmest month (average temperature of 26.9° C [80.5 °F]) and January the coldest (average temperature of -1.1 °C [30.1 °F]). Sudden temperature changes are infrequent, mainly due to the moderating effect of the mountains (NOAA, 1994).

Precipitation is well-distributed over the year with an average annual precipitation of 134.1 cm (52.8 in.). August, September and October are generally the driest months with average rainfalls of 8.9 cm (3.5 in.), 3.3 cm (1.3 in.), and 3.2 cm (1.3 in.), respectively. Peak rainfall occurs during March (average of 14.9 cm [5.86 in.]), December (average of 12.9 cm [5.09 in.]),and July (average of 12.9 cm [5.08 in.]) (NOAA, 1994).

Temperature extremes and freeze data for 1994 from the Lenoir City weather station indicate that the length of the growing season is approximately 236 days. The earliest recorded freeze date for that year was in mid-November and the latest in early April (NOAA, 1994).

4.0 METHODS

4.1 Shoreline Site Selection

Thirty sites were selected for sampling with quadrats between May and August of 1996. Fifteen sites were located in the riparian shoreline habitat and 15 in the mesic shoreline habitat. Figure 4.1 shows quadrat location along Watts Bar Reservoir. These sites were selected using two criteria: (1) biotic and abiotic characteristics, and (2) practicality. The first criterion has six characteristics. First, the shoreline had to contain a visibly mature forest stand that showed minimal signs of post-impoundment disturbance. Appendix B contains a checklist of habitat disturbance indicators that was used to evaluate this characteristic. Stand age was approximated based on historical record, stand age data from compositionally-similar stands located in comparable habitats (Smith et al., 1975), and species-specific growth rate and form expectations (Burns and Honkala, 1990). Initiation of forest stands in riparian habitats could reasonably be dated from the closing of the dam in 1942 due to marginal clearing of vegetation (Section 2.3). Forest stands in mesic habitats were required to be, minimally, of a comparable age (i.e., 30-50 years) to those selected from riparian habitats.

Second, the distance from the shoreline to the back edge of the stand had to be wide enough to provide a closed canopy so that the second rank of tree species was shade-limited by at least one subsequent tree rank (i.e., a double-edged forest strip was not acceptable). Third, the shoreline was required to be fully exposed to wave impacts from unrestricted boat traffic on the channel sail line (i.e., the shoreline could not be located in the lee of a protecting point or islet). Fourth, the shoreline scarp could not be rock-defended. Fifth, the shoreline slope was limited to less than 50%.

Finally, variation in the topography of the shoreline site had to be limited to the extent that the latter could be classified either as a riparian (i.e., depth-to-pool incursion < 0.5 m) or a mesic (i.e., depth-to-pool incursion ≥ 0.5 m) habitat. The potential site could not contain both types of

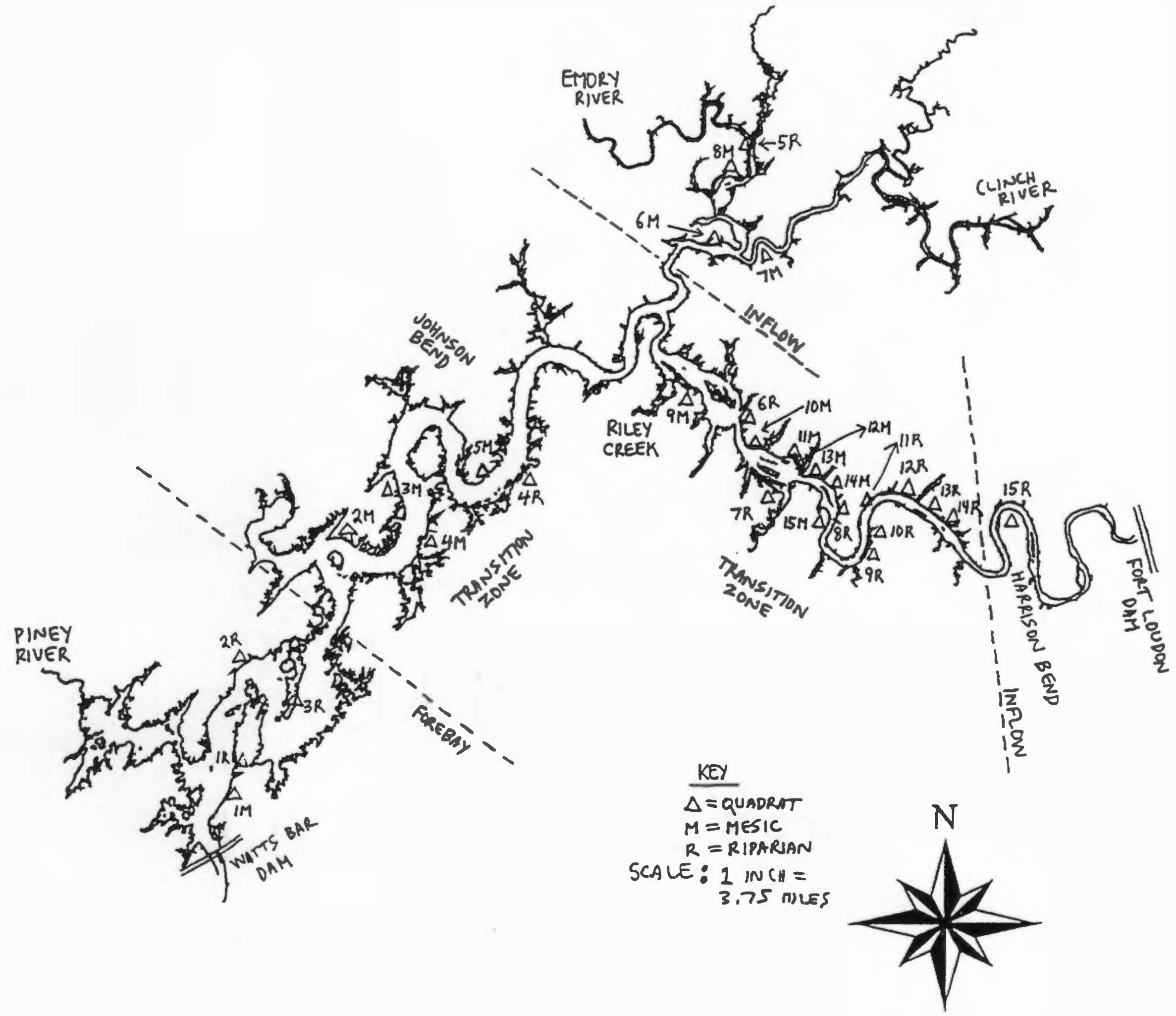


Figure 4.1 Quadrat and Sampling Zone Locations along Watts Bar Reservoir

habitats. This was determined by first identifying sites with highly homogeneous-appearing slope and scarp contours on boat reconnaissance trips. This was followed by an onshore evaluation of the site's topographic variation that included taking pairs of slope and scarp height measurements along the site's shoreline edge. Scarp height was normalized for the summer reservoir pool level (225.9 m msl). For this initial assessment, measurements were taken, minimally, at the mid- and endpoints on the site's edge and along any point on the edge with an apparent slope or scarp irregularity. Depth-to-pool incursion four meters slopeward from the reservoir pool (Figure 4.1) was estimated using a formula that required slope and scarp height measurements. This formula and its geometric derivation are provided in Appendix C. A candidate site was required to have estimated depths that either categorically met the depth-to-pool incursion criteria for a riparian site or for a mesic site.

The feasiblity criterion encompassed site accessibility and personal safety. Over half the quadrats were reached by kayak. Thus, quadrats had to be located on shoreline sites that were proximal to feasible "put-in" areas (i.e., close enough so that one-way paddle-time would not exceed one hour). In addition, it was preferable to avoid sites requiring channel-crossing.

Preliminary reviews of navigational and land use maps and off- and onshore reconnaissance were used to determine if shoreline site selection criteria were met. Within the constraints of meeting these criteria, an attempt was made to distribute sites along the reservoir. The reservoir was divided into three areas used by TVA for its aquatic monitoring program: (1) an inflow area that is generally riverine in character; (2) a transition area in which water velocity decreases due to increased cross-sectional area; and (3) a forebay area that is the lacustrine area near Watts Bar Dam (Dycus and Meinart, 1994). Since TVA monitored specific points within these zones and did not define their boundaries, the exact areal extent of their zones is unknown.

For the purpose of this research, zonal boundaries were distinguished with the assistance of TVA personnel and by map interpretation and reservoir reconnaissance. These are shown in Figure

4.1. The number of quadrats in each zone were approximately proportional to the area covered by that zone (e.g., 21 [70%] of the sites were located in the transition zone which accounts for approximately 63% of Watts Bar Reservoir).

4.2 Quadrat Location and Description

After a potential shoreline site was found to meet selection criteria, a quadrat was located on the site using a procedure intended to reduce bias. From the point where it was most practical to disembark, the first pole (pole-sized tree defined as 2.5 cm $\leq$ DBH < 12.5 cm) located two meters inland was used as a quadrat endpoint.

Each quadrat was 4 m wide x 25 m long and was located along the pool with the lengthwise edge being the summer pool line (225.9 m msl) (Figure 4.2). Quadrat width was not corrected for slope. Prior research has demonstrated that rectangular plots furnish a more accurate analysis of the composition of a vegetation stand than the same number of square plots having the same area (Cox, 1985).

A quadrat area of 100 m^2 was chosen using forest sampling guidelines provided by Oosting (1956). A species-area curve was plotted (i.e., cumulative number of canopy species plotted against cumulative number of quadrats) to ensure that the number of quadrats taken sufficiently encompassed species richness in each habitat. Results showed that species richness in the mesic and riparian habitats quickly rose in the first 11 and nine quadrats, respectively. The curves then leveled off for each, indicating that 15 quadrats were sufficient to encompass taxal heterogenity in both habitats.

4.3 Data Acquisition

Using a 100 m^2 quadrat, physical and vegetation field data were collected following the layout provided in Figure 4.2. Quadrat slope and edge scarp height and form were taken at five points along the shoreline at the summer reservoir pool level (225.9 m msl), designated as "A" (front

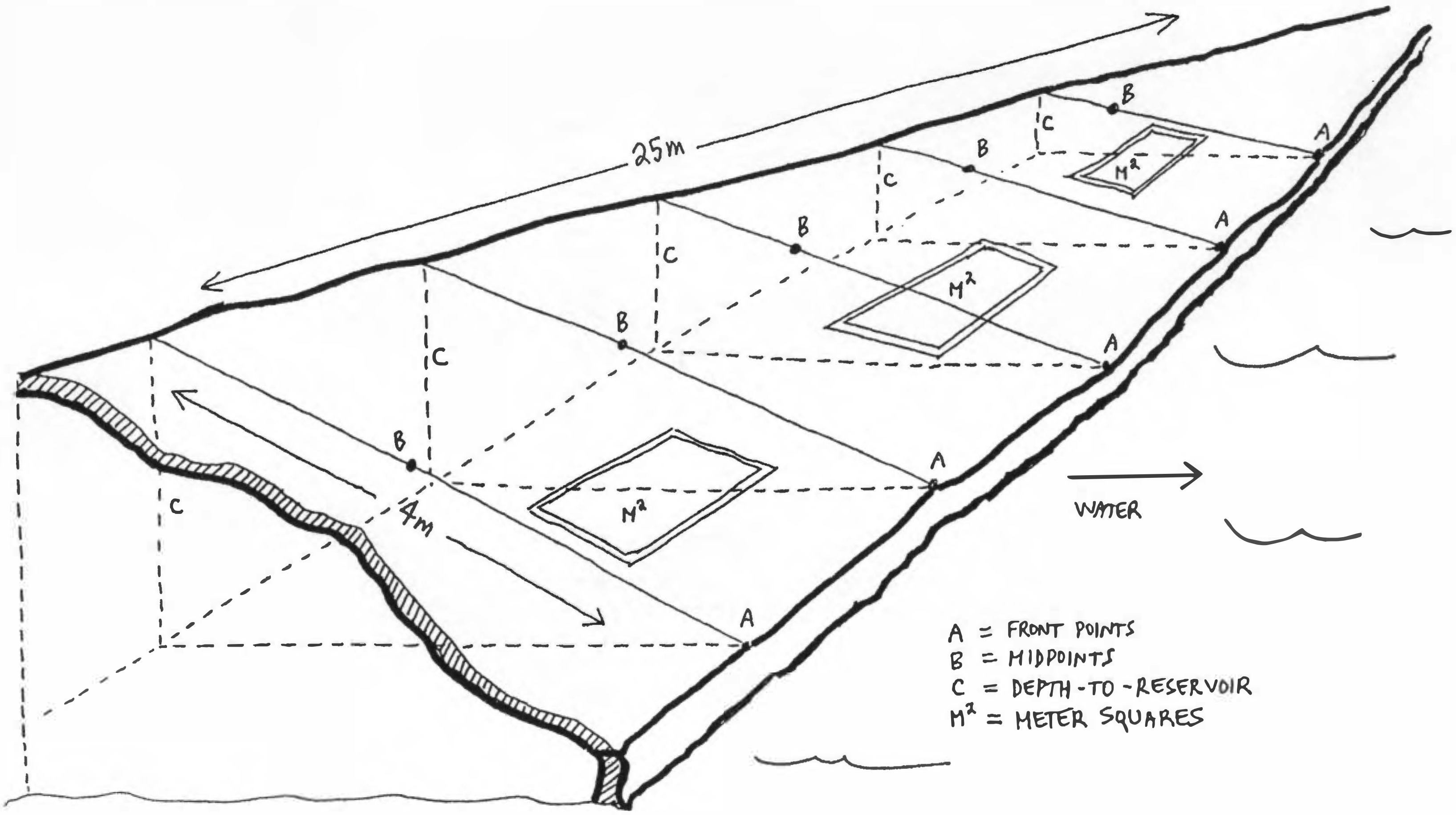


Figure 4.2 Schematic of Quadrat Layout

points) in Figure 4.2. A Suunto clinometer was used to measure quadrat slope. Scarp height was measured using a meter stick. Scarp form was described and classified into one of four general categories adapted from Brinson et al. (1981): concave scarp with root mat overhang; concave scarp without root mat overhang; convex scarp; and vertical scarp.

Vegetation data were acquired for canopy, subcanopy, and sapling/shrub/liana (also collectively referred to as 'low-profile') strata. Canopy data included species identification and diameter at breast height (DBH) measurement of trees (defined by a DBH $\geq$ 12.5 cm). Subcanopy vegetation data included number of poles by species.

Canopy and subcanopy data were collected over the entire 100 m^2 area. At the quadrat edge, only trees and poles at least half of their bases in the quadrat were counted. Those trees located at water's edge that leaned out of the quadrat over the water (but whose bases were located within the quadrat) were also included. Conversely, if a tree leaned into the quadrat but more than 0.5 of its base was located outside the quadrat, then it was not included. Sapling, shrub, and woody vine vegetation were sampled in three 1 m^2 subplots (Figure 4.2) using a modification of Daubenmire (1959) coverage class. Presence/absence data for this stratum were collected over the entire 100 m^2 quadrat.

Species were first identified in the field and samples were taken for later verification in the laboratory. B.E. Wofford, curator of The University of Tennessee Herbarium, verified samples. Species identification and verification followed nomenclature used in Radford et al. (1964) or Wofford (1989). Pressed specimens remain in the possession of C. C. Amundsen, Department of Ecology and Evolutionary Biology, The University of Tennessee, Knoxville. Due to insufficient sampling of *Celtis occidentalis* and *C. laevigata*, and their potential misidentification in the field, both were identified as *Celtis* spp. Differentiation of *Fraxinus americana* and *F. pennsylvanica* in the field was based on habitat per suggestion of B. E. Wofford: In the Watts Bar Reservoir region, the former is generally located in a mesic habitat while the latter is found in a riparian habitat (personal communication, 1996). Several oak species common to this region readily hydridize with other oak species (e.g., *Quercus rubra)* (Burns and Honkala, 1990). Due to the impracticality of identifying hybrids in the field, oaks were generalized to the species level based on their characteristics that most closely matched taxonomic descriptions provided by Radford et al.(1964).

Canopy closure and edge closure measurements were taken at midpoints designated as "B" in Figure 4.2. A spherical crown densiometer (Lemmon Densiometer) was used to measure canopy closure. Density of vegetation adjacent to the pool was measured by a perceived shoreline edge closure method. Standing at each of these points, the density of the edge closure was estimated at eye level by looking through a gridded 0.3 m^2 metal frame and estimating the percent visual coverage of the reservoir channel. Canopy height was measured using an Suunto clinometer.

4.4 Data Analysis

4.4.1 Physical Measurements and Depth-to-Pool Estimates

Each of the five pairs of scarp height and slope measurements taken along the shoreline edge of each quadrat was used to determine an estimated depth-to-pool incursion four meters slopeward from the reservoir. Scarp heights were first normalized for the summer pool level (225.9 msl). Each pair of measurements was then used to calculate estimated depth-to-pool incursion (Appendix C). Means, ranges, and standard deviations for each set of five slope and scarp height measurements and the set of five depth-to-pool estimates were calculated for each quadrat.

4.4.2 Descriptive and Nonparametric Vegetational Analyses

Analyses of vegetation data were conducted first to separately characterize the sampled stands located in the shoreline mesic and riparian habitats, and then to determine their similarities and significant differences. Using data obtained from each type of habitat (n = 15), the following calculations were made. Basal area was calculated for the canopy stratum by species and by the following tree size classes: total, 12.5-20, 21-30, 31-40, 41-50, 51-60, > 60 cm DBH. Relative basal area and relative frequency were calculated in order to determine species importance value 200 (relative basal area + relative density) by quadrat and by habitat.

Species diversity and equitability were determined for canopy and subcanopy strata, while species richness was calculated for these and the low profile stratum. Species diversity was computed using the Shannon Index of General Diversity (H') using the formula:

Equation 1. $H' = \sum (p_i - \ln(p_i))$

where p_i = decimal fraction of importance probability of individual species (McCune and Mefford, 1995).

The equitability index (E) (evenness) was calculated using the formula:

Equation 2. $E = H'/\ln(\text{richness})$

where H' is the Shannon Index of Diversity and richness is the number of species found in each habitat (McCune and Mefford, 1995).

From data derived from m^2 samples (45 per habitat), cover frequency indices were calculated for low-profile species in each habitat. Indices were calculated by multiplying the average Domin-Dahl (D-D) abundance-coverage values for each species by the percent frequency (PF) of occurrence out of the total number of samples taken (45 per habitat) (Amundsen, 1977).

Sørenson Coefficient of Community (CC), an index of species similiarity, was used to determine species similarity in strata within and between forest stands (i.e., riparian and mesic). This index was calculated using the formula:

Equation 4. $CC = 2c/(a + b)$

where c = number of species shared by two sites (or strata) and a + b = sum of species in both sites (Jongman et al., 1995).

Sørenson CC was applied to species presence lists that were composites of species represented in all sampled stands within a habitat. That is, the similarity in riparian and mesic presence lists was determined. When a CC assessment was conducted to determine similarity in stand strata within a habitat (e.g., canopy and subcanopy species and then subcanopy and low-profile species), only potential canopy species were included. For example, bushes were not included when comparing the similarity in low-profile and subcanopy strata species. Also taxa were identified only to the level reasonable for identification in the low-profile stratum. Hickories were identified by genus and oaks by group, *sensu* Peterson's Field Guide (Petrides, 1988).

A nonparametric statistical test, the Mann-Whitney U test (SPSS, 1995) was employed to determine significant differences amongween characteristics of habitat forest stands. These characteristics were: basal area for the canopy stratum; diversity and equitability for the canopy and subcanopy strata; richness for each stratum; and vegetation structure (e.g, canopy height and closure; edge closure). Differences between strata characteristics (e.g., diversity in canopy and subcanopy species) in stands within a habitat were also assessed using Mann-Whitney. Results from Mann-Whitney were considered significant at less than or equal to 0.05.

4.4.3 Cluster Analysis: TWINSPAN

Canopy vegetation data were further described using a polythetic divisive clustering technique. This type of cluster analysis takes into account all species as a single initial cluster (polythetic) and proceeds to partition it into smaller clusters until each cluster contains no more than a specified number of samples (divisive). Its benefit is that it uses "all the available information...to make the critical topmost divisions" (Gauch and Whittaker, 1981).

TWINSPAN, one of the most widely used polythetic divisive clustering techniques, was selected for this analysis and was applied to a "quadrat x canopy species importance values" matrix data set. TWINSPAN was performed with the PC-ORD Software Package which uses a modified version of TWINSPAN from the Cornell Ecology Program series (McCune and Mefford, 1995).

TWINSPAN analyzes presence/absence data to conduct a series of site and species ordinations that are used as part of the cluster analysis. To approximate quantitative abundance data, it creates a variable number of "pseudospecies" that represent abundance classes. The "pseudospecies cut levels" are used to define the ranges of these abundance classes (McCune and Mefford, 1995). Since species importance values ranged from 0 to 200, five cut levels (0, 5, 10, 20, and 40) were used to reflect the range common to these data. With the exception of this program setting, all other default values were used.

TWINSPAN initially ordinates quadrats by the method of correspondence analysis. This method is analogous to reciprocal averaging. Reciprocal averaging is an iterative process that basically involves two steps: site scores were averaged to obtain species scores and, reciprocally, species scores were averaged to obtain site scores (Hill, 1973). The result of reciprocal averaging is a stable point where there is such a minimal change in species scores that the newest set of site scores is essentially the same as the previous set. These scores constitute the first axis.

The initial division of quadrats in TWINSPAN is made at the center of the first correspondence analysis ordination axis. Species preference scores are assigned based on species preference for the positive or negative side of this split axis. The weighted species preference scores and the weighted site average preference scores are then used to reorder the sites and species in a procedure referred to as "refined ordination." The resulting ordination axis is split usually near its center and the procedures are repeated until the hierarchy is complete.

TWINSPAN is also referred to as "dichotomized ordination." The result of this ordination are site dendograms and an ordered two-way site-by-species matrix. TWINSPAN also identifies indicator species. These are species that best discriminate a cluster based on either their presence or absence (Jongman et al., 1995).

4.4.4 Ordination Analysis: DCA

Canopy species data were also described in relation to environmental gradients. This was done by applying indirect ordination, a technique that uses hypothetical environmental gradients to explain principal patterns of variation in vegetation data. Detrended correspondence analysis (DCA), a widely used ordination technique, was selected for this analysis and was applied to a "quadrat x canopy species importance values" matrix data set. DCA was performed with the PC-ORD Software Package which uses a modified version of DECORANA from the Cornell Ecology Program series (McCune and Mefford, 1995).

DCA is a refinement of correspondence analysis involving an iterative site-species averaging procedure which results in a stable set of plot scores constituting its first ordination axis. A second axis is derived by the same iteration, with one additional procedure. The trial scores for the second axis are made uncorrelated from the scores of the first axis by plotting a regression of the two axes' scores and using the residuals as the new scores. If this was not done, the iteration process would result in the first axis previously derived. Additional axes may be derived using this same procedure (Jongman et al., 1995).

DCA is identical to correspondence analysis except that it includes a rescaling of axes and a "detrending" procedure. The reader may refer to Hill and Gauch (1980) for the rationale and description of this procedure. One of the results of DCA is a diagram in which quadrats and species are represented by points in a two-dimensional ordination space. The distribution of quadrat points along an axis may be interpreted as the change in species composition along an environmental gradient. Quadrat points that are close together are generally similar in species composition, while quadrat points that are far apart are generally dissimilar. The distance between the sites is a chi-squared distance metric, although this calculation is not explicitly done by DCA (McCune and Mefford, 1995).

The possibility that the "hypothetical environmental gradient" represented by the first axis was related to the depth-to-reservoir pool incursion in this study was explored qualitatively and quantitatively as recommended by Jongman et al. (1995). Depth measurements were recorded on the ordination diagram by the sites and were visually examined for data trends (e.g., did depth-to-reservoir pool incursion increase along the environmental gradient?). Using the PC-ORD program, Pearson and Kendall's tau-b correlation statistics were also calculated. Depth-to-pool incursion was the independent variable and the axis site score was the dependent variable.

Pearson's correlation statistic assumes a normal distribution of data. Since only a limited number of species were found to exhibit normality, Kendall tau-b, a nonparametric correlation statistic, is preferrable. However, if one accepts the possibility of an increase in Type 1 errors, Pearson's statistic may also be used for interpretative purposes (Steel and Torrie, 1980).

5.0 RESULTS AND DISCUSSION

This chapter describes and analyzes the results of this research by first depicting physical characteristics and then describing compositional and structural characteristics of the sampled forest edges.

5.1 Physical Characteristics

5.1.1 Depth-to-Pool Incursion

Estimated depth-to-reservoir pool incursion was based on shoreline geometry: slope, scarp height, and the assumption that there was a horizontal sublateral incursion of the reservoir pool across the four meters wide undefended shoreline quadrat. Figure 5.1 presents the estimated hydric depths for each of the 30 quadrats. Means, ranges, and standard deviations of the five slope and scarp height measurements and depth-to-pool estimates for each quadrat are provided in Appendix D. Quadrats located in riparian habitats had a mean depth of 0.23 m, with a range from 0.03 m (Quadrat 6R) to 0.49 m (Quadrat 15R). Quadrats located in mesic habitats had a mean depth of 2.7 m, with a range from 1.9 m (Quadrat 7M) to 4.1 m (Quadrat 14M). The range of depth-to-pool incursion estimates was less than 0.25 m for four riparian and ten mesic quadrats, indicating that their topography was less variable in slope and scarp height.

5.1.2 Quadrat Edge Erosion Observations

Varying scarp forms along quadrat edges suggested that banks were in various eroded stages. Figure 5.2 depicts the general scarp forms observed in the mesic and riparian habitats. Thirty-three percent of the mesic quadrats had scarps identified under Form 1M. Root masses generally extended over the edge of the scarp for a minimum distance of 0.5 m. Thirty-three percent were categorized as Form 2M. These scarps were higher, generally appearing as a vertical-to-slightly concave red clay wall. Overhangs were less common and tilted and fallen vegetation occurred more often. Thirteen percent of the quadrats had Form 3M scarps. This scarp form was the result of bank

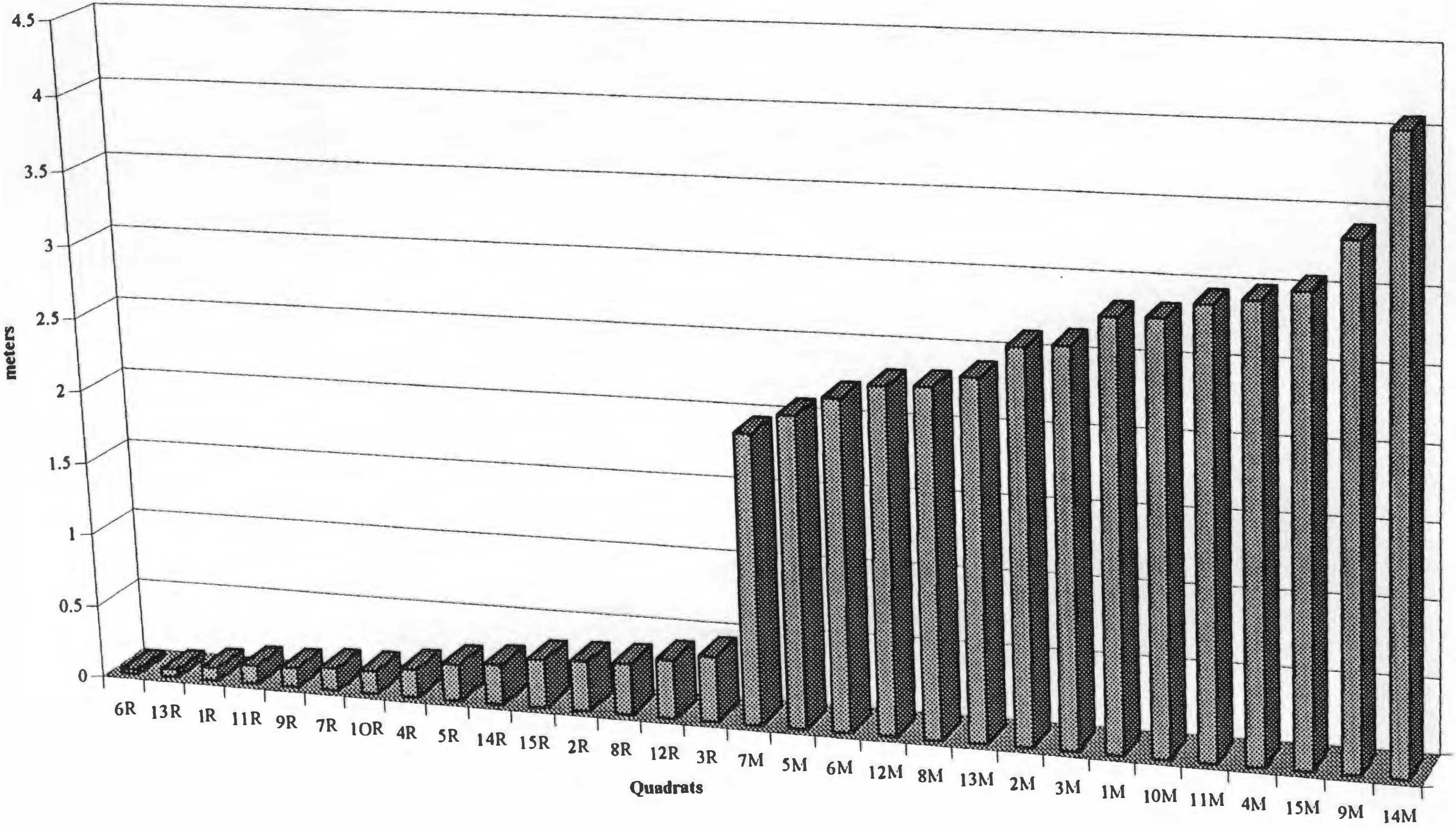
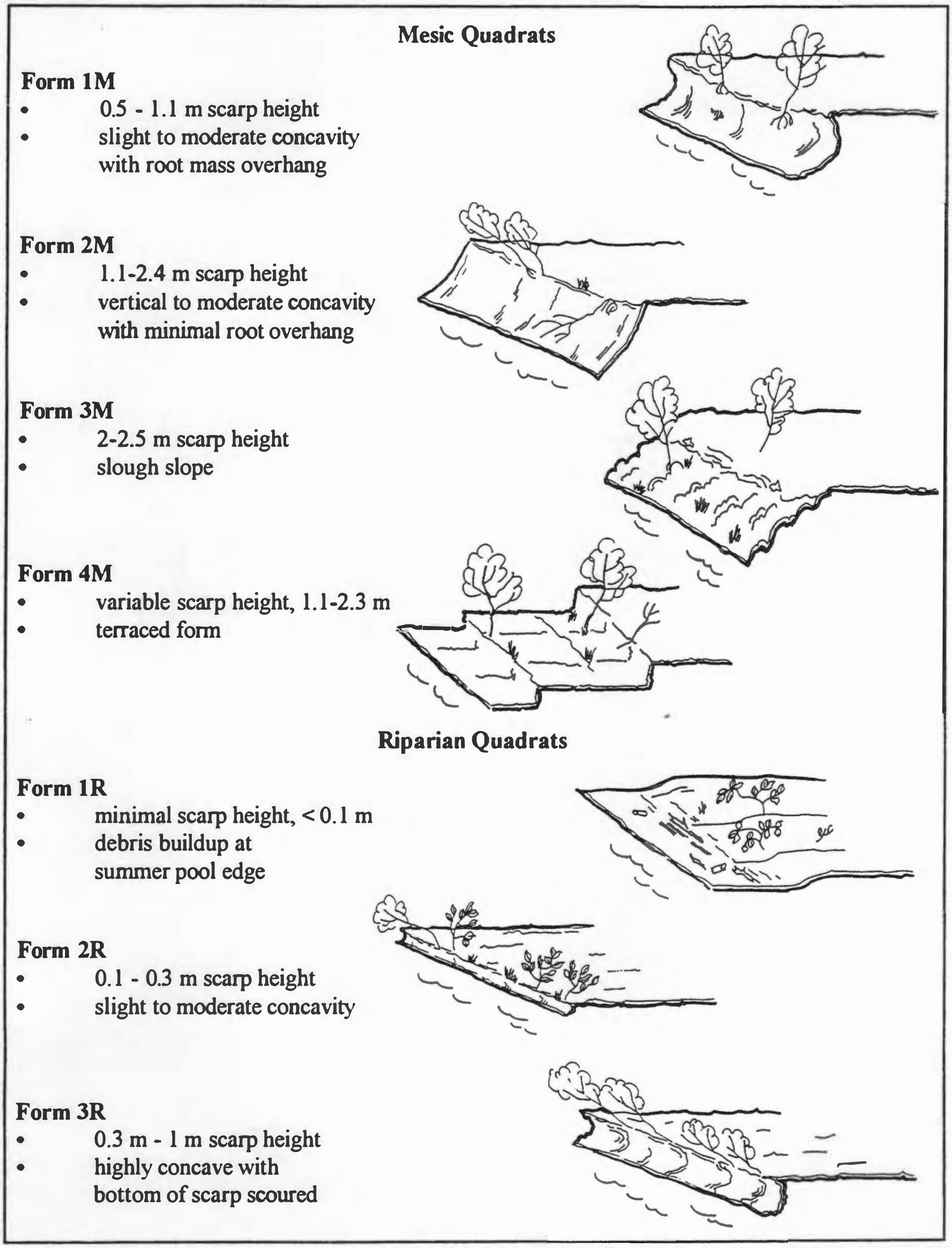


Figure 5.1 Estimated Depth-to-Pool Incursions for Quadrats Located in Riparian and Mesic Habitats



[1]Scarp height measured from base.

Figure 5.2 Mesic and Riparian Quadrat Scarp Forms[1] failure and subsequent sloughing. Vegetation cover on the slough slope generally ranged from grasses to poles and periodically contained trees that slid with scarp collapse. The remaining mesic quadrats (20%) had 4M scarps. These were terraced, with vegetation on the set-back ranging from grasses to poles. Observations of increasing scarp height, undercutting, collapse with sloughing, and terracing generally conform to scarp form evolution stages identified by Simon and Hupp (1987).

Fifty-three percent of the riparian quadrats had Form 1R scarps with woody debris, organic litter, and frequent flotsam buildup along their edges. Twenty-six percent had Form 2R scarps with overhangs that were either root-bound soil shelves or soil-free root masses. The remaining riparian quadrats (20%) had Form 3R scarps. These scarps were extensively undercut, creating a more extended and unstable overhang. In general, exposed root masses on the riparian quadrat scarp faces generally did not extend below the summer reservoir pool level (225.9 m msl).

5.2 Forest Stand Composition and Structure

This section depicts and compares sampled mesic and riparian shoreline stands that are, in part, based on sampled stand data that have been analyzed by habitat and by stratum. Results of these analyses are provided in Tables 5.1 through 5.5 and Figures 5.3 and 5.4. Table 5.1 identifies importance values of canopy species. Table 5.2 depicts relative frequency and density of the subcanopy species (poles). Tables 5.3 and 5.4 describe sapling, bush, and liana species. The former provides an index of importance based on species identified in the m^2 plots while the latter depicts their percent occurrence (i.e., number of quadrats in which species are present per habitat) based on species presence over the 100 m^2 quadrat.

Table 5.5 presents compositional (i.e., richness and diversity) and structural characteristics (basal area, density, canopy height and closure, and edge closure) by habitat for each stratum. Figures 5.3 and 5.4 further depict mesic and riparian stand structures by tree size classes (DBH in cm). The former shows tree basal area distribution, while the latter depicts tree and pole density

Table 5.1 Importance Values of Canopy Species in Forest Stand Edges Located in Mesic and Riparian Reservoir Shoreline Habitats

Mesic Habitat		Riparian Habitat	
Species	IV 200	Species	IV 200
Quercus rubra	42.7	*Acer saccharinum*	82.0
Liriodendrum tulipifera	17.7	*Platanus occidentalis*	29.5
Liquidambar styraciflua	13.5	*Betula nigra*	19.1
Quercus muehlenbergii	12.1	*Liquidambar stryaciflua*	13.6
Juniperus virginiana	10.8	*Fraxinus pennsylvanica*	12.7
Robinia pseudocacia	10.4	*Salix nigra*	10.7
Carya ovata	7.8	*Celtis spp.*	8.7
Quercus marilandica	7.6	*Ulmus rubra*	6.2
Ostrya virginiana	7.6	*Acer negundo*	6.0
Fraxinus americana	7.6	*Acer rubrum*	3.7
Quercus alba	7.5	*Pinus taeda*	1.8
Ulmus rubra	7.1	*Diospyros virginiana*	1.6
Carya glabra	6.9	*Morus rubra*	1.4
Tilia americana	6.4	*Robinia pseudocacia*	1.4
Pinus virginiana	4.7	*Ulmus alata*	1.1
Platanus occidentalis	4.4	*Juniperus virginiana*	0.7
Carya tomentosa	3.3		
Acer rubrum	3.0		
Magnolia acuminata	2.4		
Celtis spp.	2.4		
Prunus serotina	2.3		
Fagus grandifolia	2.3		
Quercus stellata	1.7		
Diospyros virginiana	1.6		
Oxydendrum arboreum	1.2		
Aesculus flava	1.1		
Cercis canadensis	0.9		
Pinus taeda	0.9		
Carya cordiformis	0.8		
Quercus falcata	0.8		
Acer negundo	0.7		

Table 5.2 Subcanopy (Pole) Species in Forest Stand Edges Located in Mesic and Riparian Reservoir Shoreline Habitats

Mesic Habitat			Riparian Habitat		
Species	RD[1]	RF[2]	Species	RD[1]	RF[2]
Ostrya virginiana	12.6	26.7	*Alnus serrulata*	30.1	66.7
Cercis canadensis	8.1	60.0	*Ligustrum sinense*	24.5	60.0
Ulmus rubra	6.9	33.3	*Cornus amomum*	15.3	53.3
Robinia pseudocacia	5.7	46.7	*Acer saccharinum*	13.4	93.3
Quercus rubra	5.1	53.3	*Ulmus rubra*	3.1	6.7
Cornis florida	5.1	40.0	*Acer rubrum*	2.6	20.0
Viburnum prunifolium	4.8	29.0	*Platanus occidentalis*	1.9	20.0
Liquidambar stryaciflua	4.8	40.0	*Fraxinus pennsylvanica*	1.6	53.3
Juniperus virginiana	4.5	33.3	*Betula nigra*	1.5	26.7
Carya tomentosa	3.6	20.0	*Amorpha fruticosa*	1.3	40.0
Acer saccharum	3.6	6.8	*Asimina triloba*	1.2	13.3
Carya glabra	3.6	26.7	*Celtis spp.*	0.7	13.3
Prunus serotina	3.3	40.0	*Acer negundo*	0.7	26.7
Quercus alba	3.3	20.0	*Salix nigra*	0.6	6.7
Acer rubrum	3.3	20.0	*Quercus phellos*	0.3	6.7
Ulmus alata	2.7	20.0	*Liquidambar stryaciflua*	0.3	6.7
Tilia americana	2.4	6.7	*Morus rubra*	0.3	13.3
Pinus virginiana	2.1	6.7	*Pinus virginiana*	0.1	6.7
Sassafras albidum	1.8	26.7			
Pinus echinata	1.5	6.7			
Fagus grandifolia	1.5	13.3			
Quercus muelenbergii	0.9	20.0			
Carya cordiformis	0.9	13.3			
Asimina triloba	0.9	20.0			
Acer negundo	0.6	6.7			
Diospyros virginiana	0.6	13.3			
Nyssa sylvactica	0.6	6.7			
Carya ovata	0.6	6.7			
Alnus serrulata	0.6	6.7			
Quercus marilandica	0.3	6.7			
Quercus phellos	0.3	6.7			
Albizia julibrissin	0.3	6.7			
Halesia carolina	0.3	6.7			
Staphylea trifolia	0.3	6.7			
Cornus amomum	0.3	6.7			

[1]RD=Relative Density: # of poles per species divided by total # of poles per habitat multiplied by 100.
[2]RF=Relative Frequency: # of quadrats in which species occurs divided by total # of quadrats per habitat multiplied by 100.

Table 5.3 Cover-Frequency Indices for Sapling, Bush, and Liana Species in Forest Stand Edges Located in Mesic and Riparian Reservoir Shoreline Habitats

Mesic Habitat	D-D[1]	F	I[2]	Riparian Habitat	D-D[1]	F	I[2]
Acer rubrum	8.8	24.4	216	*Ligustrum sinense*	6.2	55.5	342
Lonicera japonica	5.3	33.3	176	*Rhus radicans*	5.2	42.2	220
Rhus radicans	5.3	28.9	153	*Lonicera japonica*	4.5	37.8	169
Carya spp.	3.8	35.5	133	*Alnus serrulata*	6.7	24.4	164
Ostrya virginiana	5	22.2	111	*Cornus amomum*	5.7	26.7	153
Bristle-tipped Oaks[3]	5.1	20	102	*Campsis radicans*	4.6	17.8	82.2
Prunus serotina	3.9	17.8	69	*Clematis terniflora*	5	11.1	55.5
Asimina triloba	7	8.9	62	*Amorpha fruticosa*	4.6	11.1	51.1
Ulmus rubra	5.2	11.1	58	*Acer negundo*	5.5	8.9	48.8
Cornus florida	4.4	11.1	49	*Wisteria spp.*	4.7	8.9	42.2
Feather-lobed Oaks[3]	3.6	11.1	40	*Acer rubrum*	6	6.7	40
Sassafras albidum	4.5	8.9	40	*Rubus spp.*	4.3	8.9	37.7
Vitis spp.	3.6	11.1	40	*Asimina triloba*	7.5	4.4	33.3
Smilax spp.	4.3	8.9	38	*Quercus phellos*	4.5	4.4	20
Staphylea trifolia	7.5	4.4	33	*Fraxinus spp.*	4	4.4	17.7
Wavy-Edged Oaks[3]	4.7	6.7	31.5	*Smilax spp.*	3	4.4	13.3
Acer saccharum	4.7	6.7	31	*Salix nigra*	5	2.2	11.1
Ulmus alata	4	4.4	18	*Acer saccharinum*	4	2.2	8.9
Cercis canadensis	3.5	4.4	16	*Liriodendrum tulipifera*	4	2.2	8.9
Fraxinus spp.	5	2.2	11	*Vitis spp.*	4	2.2	8.9
Fagus grandifolia	5	2.2	11	*Unidentified vine*	4	2.2	8.9
Aesculus flava	4	2.2	11	*Unidentified sapling*	4	2.2	8.9
Robinia pseudocacia	4	2.2	8.9	*Bristle-Tipped Oaks*[3]	1	2.2	2.2
Quercus phellos	4	2.2	8.9				

[1]Domin -Dahl values used to estimate coverage. Column values are means of species' D-D values (i.e., sum D-D values per species/total number of quadrats in which species is present).

1 Occurring as one or two individuals with normal vigor; no measurable cover.
2 Occurring as several individuals; no measurable cover.
3 Occurring as numerous individuals but with cover less than 4% of total cover.
4 Cover up to one-tenth (4 to 10%) of total area.
5 Cover up to one-fourth (11 to 25%) of total area.
6 Cover one-fourth to one-third (26 to 33%) of total area.
7 Cover one-third to one-half (34 to 50%) of total area.
8 Cover one-half to three-fourths (51 to 75%) of total area.
9 Cover three-fourths to nine-tenths (76 to 90%) of total area.
10 Cover nine-tenths to complete 91 to 100%.

[2]Indices (I) were calculated by multiplying average Domin-Dahl (D-D) abundance-coverage values for each species by % of occurrence (F) in each habitat type (i.e., riparian and mesic). Forty-five 1 m^2 quadrats were taken in each habitat.

[3]Oak Groups *sensu* Peterson Field Guide Series (Petrides, 1988)

Table 5.4 Relative Frequency of Sapling, Bush, and Liana Species in Forest Stand Edges Located in Mesic and Riparian Reservoir Shoreline Habitats

Mesic Habitat		Riparian Habitat	
Species	**RF[1]**	**Species**	**RF[1]**
Carya spp.	80.0	*Lonicera japonica*	93.3
Ceris canadensis	80.0	*Rhus radicans*	86.7
Vitis spp.	80.0	*Ligustrum sinense*	80.0
Prunus serotina	73.3	*Cornus amomum*	80.0
Rhus radicans	60.0	*Clematis terniflora*	60.0
Acer rubrum	53.3	*Alnus serrulata*	53.3
Cornus florida	53.3	*Amorpha fruticosa*	53.3
Sassafras albidum	53.3	*Wisteria spp.*	46.7
Feather-lobed Oak Group[2]	53.3	*Rubus spp.*	40.0
Juniperus virginiana	46.7	*Fraxinus spp.*	40.0
Lonicera japonica	46.7	*Smilax bona-nox*	40.0
Bristle-tipped Oak Group[2]	46.7	*Acer negundo*	33.3
Smilax bona-nox	46.7	*Vitis spp.*	33.3
Quercus marilandica	40.0	*Betula nigra*	26.7
Robinia pseudocacia	33.3	*Acer saccharinum*	26.7
Wavy-edged Oak Group[2]	33.3	*Celtis spp.*	26.7
Viburnum spp.	33.3	*Acer rubrum*	26.7
Ostrya virginiana	26.7	*Itea virginica*	26.7
Ligustrum sinense	26.7	*Juniperus virginiana*	20.0
Ulmus rubra	20.0	*Liriodendrum tulipfera*	20.0
Liquidambar stryaciflua	20.0	*Anistichus capreolata*	20.0
Pinus echinata	20.0	*Cephalanthus occidentalis*	20.0
Oxydendrum arboreum	20.0	*Prunus serotina*	13.3
Asimina triloba	20.0	*Viburnum spp.*	13.3
Alnus serrulata	20.0	*Morus spp.*	13.3
Acer saccharum	20.0	*Rosa palustris*	13.3
Clematis terniflora	20.0	*Ulmus rubra*	6.7
Fraxinus spp.	20.0	*Liquidambar stryaciflua*	6.7
Fagus grandifolia	13.3	*Platanus occidentalis*	6.7
Amorpha fruticosa	13.3	*Robinia pseudocacia*	6.7
Ulmus alata	13.3	*Diospyros virginiana*	6.7
Campsis radicans	13.3	*Quercus phellos*	6.7
Parthenocissus quinquefolia	13.3	*Cercis canadensis*	6.7
Acer saccharinum	6.7	*Acer saccharum*	6.7

Table 5.4 Relative Frequency of Sapling, Bush, and Liana Species in Forest Stand Edges Located in Mesic and Riparian Reservoir Shoreline Habitats (continued)

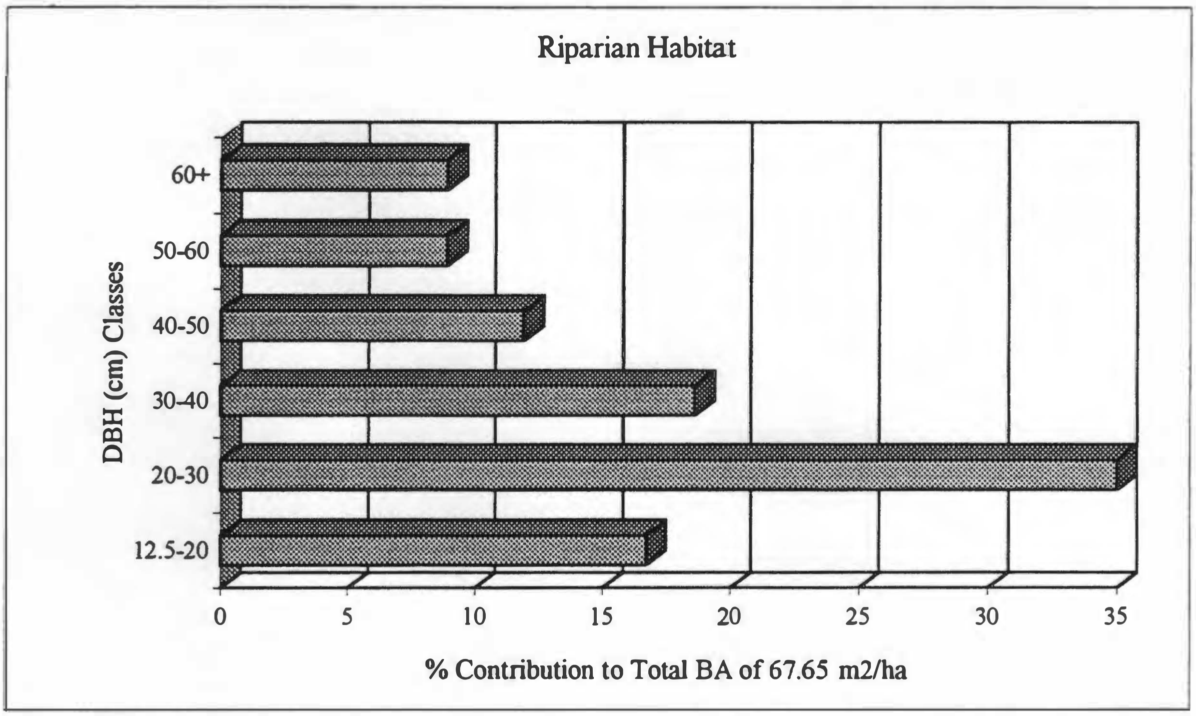
Mesic Habitat		Riparian Habitat	
Species	**RF[1]**	**Species**	**RF[1]**
Celtis spp.	6.7	*Staphylea trifolia*	6.7
Acer negundo	6.7	*Smilax glauca*	6.7
Pinus virginiana	6.7	*Bristle-Tipped Oak Group*[2]	6.7
Aesculus flava	6.7	*Carya spp.*	6.7
Tilia americana	6.7	*Wavy-Edged Oak Group*[2]	6.7
Rubus spp.	6.7	*Juglans nigra*	6.7
Wisteria spp.	6.7	*Cocculus carolinus*	6.7
Anistichus capreolata	6.7		
Hydrangea spp.	6.7		
Dioscorea villosa	6.7		
Amelanchier spp.	6.7		
Vaccinum pallidum	6.7		

[1]RF=Relative Frequency: # of quadrats in which species occurs divided by total # of quadrats per habitat multiplied by 100.
[2]Oak Groups *sensu* Peterson Field Guide Series (Petrides, 1988)

Table 5.5 Structural and Compositional Characteristics of Forest Stand Edges Located in Reservoir Mesic and Riparian Shoreline Habitats

	Mesic Habitat	**Riparian Habitat**
Canopy		
Total Richness (CC = 0.33)[1]	31 species	16 species
Average Richness per Quadrat	5.3 species	3.7 species
Average Diversity per Quadrat	1.3	.93
Average # of Trees per Quadrat	11.0	13.0
Average Basal Area	63.9 m^2/ha	67.7 m^2/ha
Subcanopy		
Total Richness (CC = 0.34)[1]	36 species	18 species
Average Richness per Quadrat	7.6 species	5.3 species
Average Diversity per Quadrat	1.7	1.1
Average # of Poles per Quadrat	22.2	45.7
Sapling, shrub and lianas		
Based on m^2 plots (45 per habitat)		
Total Richness (CC = 0.52)[1]	28 species	24 species
Average Richness per m^2 plot	3 species	3 species
Based on Presence Listing		
Total Richness (CC = 0.64)[1]	48 species	43 species
Average Richness per Quadrat	13.1 species	8.4 species
Vegetation Structure		
Average Canopy Height	19.2 m	15.7 m
Average Canopy Closure	86%	79%
Average Edge Closure	57%	75%

[1]Sorenson CC index of similarity between mesic and riparian taxa.



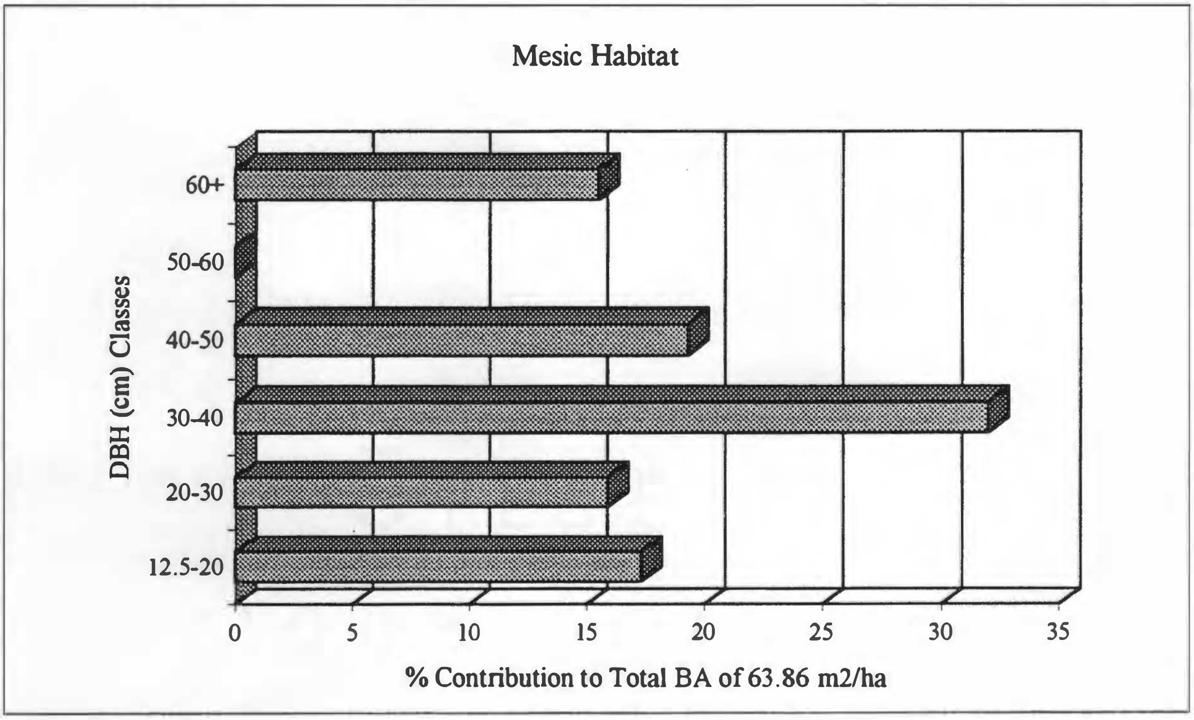
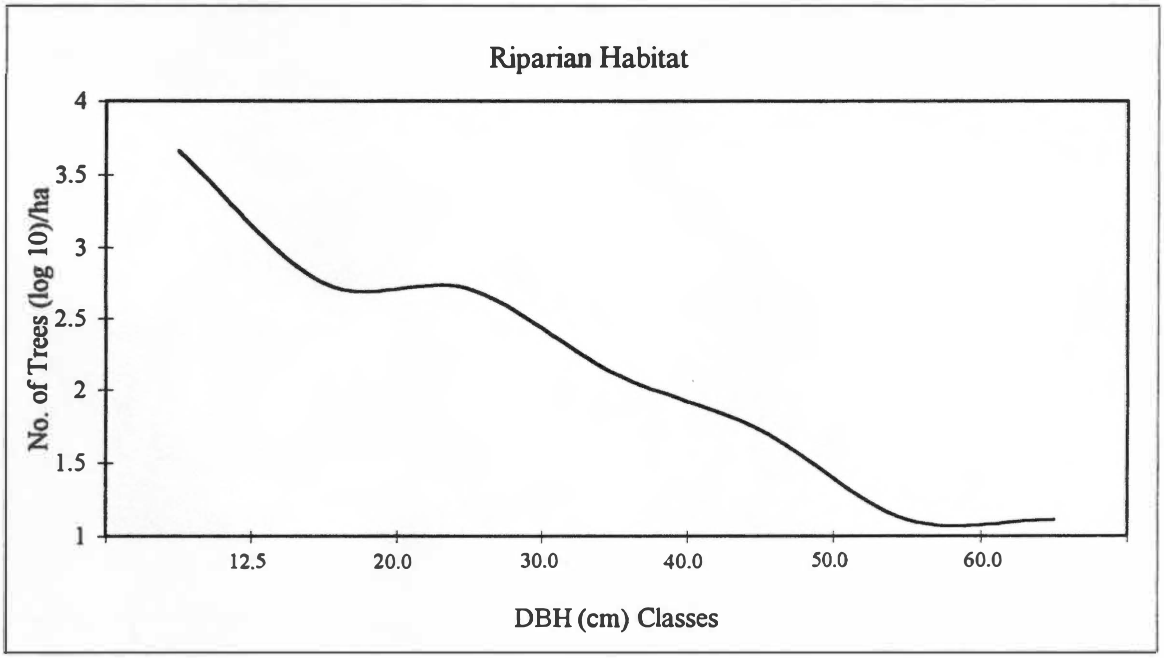


Figure 5.3 Basal Area Distribution by Size Class of Forest Stand Edges in Reservoir Shoreline Habitats



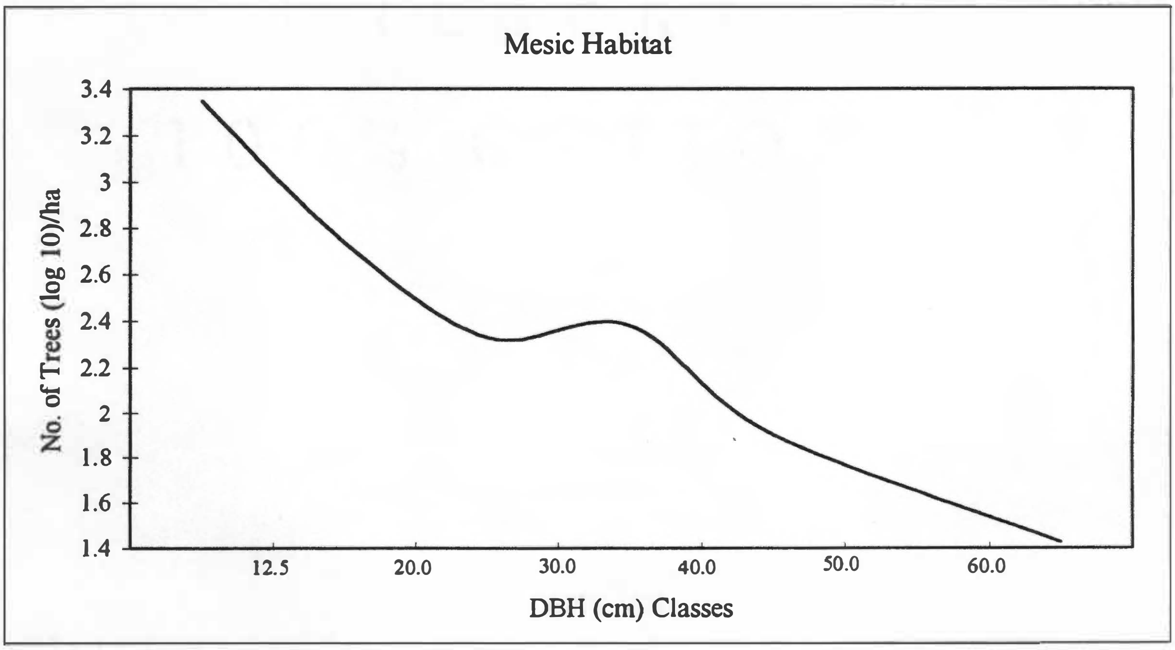


Figure 5.4 Density Distribution by Size Class of Forest Stand Edges in Reservoir Shoreline Habitats

distribution.

Quadrat-specific vegetational descriptions are provided in the appendices. A general description of each is provided in Appendix E. Appendix F contains importance values for canopy species by quadrat, while Appendix G provides a listing of species present in all strata, their growth form, and their habitat occurrence. Appendix H contains, by quadrat, canopy height and means, ranges, and standard deviations for canopy closure and edge closure measurements.

5.2.1 Mesic Shoreline Forest Stands

Sampled forest stands in the mesic habitat were found to exhibit characteristics typical of the central portion of the Ridge and Valley Province hardwood stands (Braun, 1950; Kuchler, 1964; Martin, 1971; TVA, 1984; Bailey, 1995). Oak and hickory taxa predominated in a canopy stratum (*Quercus* spp. IV = 72.4 and *Carya* spp. IV = 18.8) composed of 29 hardwood taxa (Table 5.1). Using the species codominant construct for forest type identification, the sampled stands are collectively a red oak-tulip poplar community. *Quercus rubra* has been recognized as a dominant in the Appalachian Oak Forest (Kuchler, 1964) and *Liriodendrum tulipfera* as both a complex and a common codominant in Ridge and Valley Province forest stands (Table 2.1) (Martin, 1971).

Both codominants are commonly found in areas with deep, fertile, moist, well drained soils and are rarely found in permanently wet habitats (Burns and Honkala, 1990). Slope position and soil quality (described by Olsen [1938] as "intermediate" between good bottom- and poorer uplands) of the selected mesic shoreline sites appear to meet soil and moisture requirements of these species. Site factors that have been shown to account for most of the variation in the relative basal area of *Q. rubra* include moderate slope angle, water availability and increased soil depth (Martin, 1971). *L. tulipfera* has been shown to generally grow well on lower slopes and has been associated with soil characteristics related to soil moisture (Auten, 1945; Burns and Honkala, 1990).

These codominants' inability to tolerate persistently wet environments is inferred by their assignments under varying hydric tolerance lists. Using the U.S. Fish and Wildlife's hydric tolerance lists (Teskey and Hinckley, 1978b), each codominant is categorized as "intolerant" to inundated conditions during the growing season. *Q. rubra* is identified as FACU (i.e., 1-33% probability of occurrence in wetlands) and *L. tulipfera* as FAC (i.e., 34-66% probability of occurrence in wetlands) on the National Wetland List (Reed, 1988). This indicates the latter's preference for moister soils. Using Loy's (1994) tolerance categories (Table 2.2), each species is identified "moderately tolerant" to hydric conditions in the Watts Bar riparian habitat.

A red oak-tulip poplar community located in a county adjacent to the study area (i.e., Knox) was described as having site conditions (Martin, 1971) similar to those of the mesic shoreline habitat. The community was located in a mesic habitat with an average slope of 32% and deep soils with a high silt content. This is equivalent in average slope to those of the mesic quadrats. *Liquidambar styraciflua* was identified as the third dominant species in both the Watts Bar mesic and Knox County communities.

Preimpoundment land use may have affected species composition of the mesic sites. *L. tulipfera* has been shown to dominate areas that were previously cleared for agriculture or logged (Pyle, 1988). Given that approximately 50% of the pre-impoundment Watts Bar shoreline area was used for agriculture, it is probable that some of the sampled mesic stands established in fields after the closing of the Dam. Logging also occurred throughout this area (Olsen, 1938).

Successionally, *L. tulipfera* is a pioneer species and is subsequently replaced by species that are more shade tolerant (e.g., oaks and hickories). It appears that this process may have occurred along the shoreline. Although this species was identified as a mesic codominant, it was neither identified in the subcanopy or low-profile stratum of the sampled mesic stands. This suggests that the *L. tulipfera* is not reproducing itself and is being replaced by other species.

Edge effects may have also influenced species composition of the sampled stands. Wales

(1972) and Ranney (1971) found that species intolerant to shading were prevalent along edges. *L. tulipfera* is considered shade intolerant and an early invader in disturbed habitats (Martin, 1971; Burns and Honkala, 1990). Others species identified in the canopy strata that are considered intolerant to shading include *L. styraciflua*, *Fraxinus americana,* and *Prunus serotina*. (Wales, 1972; McKnight, et al., 1981). Species-dependent characteristics that provide competitive advantages at edges include development of pronounced lateral branching and root or stump sprouting (Ranney, 1981). *Q. rubra* demonstrates the former attribute while *Tilia americana* shows the latter (Ranney, 1981; Burns and Honkala, 1990). This characteristic of *T.americana* was observed in Quadrat 15R. From a single base, there were two primary boles (DBHs = 44.0 and 48. 5 cm) and two tree- (DBHs = 17.0 and 17.0 cm) and eight pole-size basal sprouts.

The dominant subcanopy species by relative density (Table 5.2) was *Ostrya virginica*. This species has been identified as ubiquitous, preferring neither edges nor interiors (Ranney, 1971). It has also been identified as a shade-tolerant and common understory species (McKnight et al., 1981). The distribution of *O. virginica* was limited to four quadrats (6M, 10M, 13M, and 14M) that had an average canopy closure of 86%. This aggregate under highly closed canopies is consistent with this species characteristic tolerance for shaded conditions.

Acer rubrum dominated the low profile stratum (Table 5.3) which may partially be explained by its minimal light requirements for seed germination (McKnight et al., 1981; Burns and Honkala, 1990). In relation to other species, its importance decreased in the subcanopy (based on relative frequency and density - Table 5.2) and further declined in the canopy (based on importance value 200 - Table 5.1). Although *A. rubrum* has been identified as a dominant species in forest edges (Wales, 1972), it appears that in these sampled stands it loses its early vigor as competition increases in the upper stratum.

Species similiarity from one stratum to another is both an indicator of stand stability indicating canopy species replacement and strata interactions suggesting level of competition among species from one stratum to the next. Similarity index values in canopy and subcanopy species and those in the subcanopy and low-profile strata were 0.78 and 0.65, respectively. These levels are sufficiently high to indicate canopy replacement and, therefore, some semblance of stand stability.

Species present which reduced strata similarity included those typically found in riparian habitats (e.g., *Acer saccharinum*, *Acer negundo)*. These species were limited to the low-profile and subcanopy strata, suggesting their long-term inability to successfully compete with species better adapted to mesic conditions. Other species that reduced similarity were those more commonly associated with the subcanopy than the canopy stratum (e.g., *Cornus florida*, *Sassafras albidum*).

A comparison between species diversity in sampled stand canopies and subcanopies showed the former was significantly less diverse than the latter ($\alpha = 0.008$). The mesic canopies contained fewer species than the subcanopies which included canopy-potentials, understory-limited (e.g., *Viburnum* spp., *Staphylea trifolia)* and shade-tolerant *(Cercis canadensis, C. florida)* species.

A total of 40 taxa was identified in the canopy and subcanopy strata of the mesic habitat stands. This richness may have been influenced by edge location. Forest edges have been found to have a greater species richness than forest interiors (Ranney, 1971). This has been, in part, attributed to greater intra-stand transport resulting from an increased number of propagules produced and dispersed along forest edges. Increased propagule production is a consequence of higher edge productivity. Increased propagule dispersal is a result of increased edge exposure to wind and an increased number of propagule vectors utilizing edges as corridors for movement and foraging (Ranney, 1971). Ranney also suggested that increased edge richness may be transient in edges that eventually close (i.e., advancing edges), but may be retained in edges that are maintained (i.e., cantilevered edges). If true, then increased richness in reservoir forest edges should be sustained over time since the reservoir pool dynamic maintains the forest edge's cantilever form.

Average basal area for canopy species was 63.4 m^2/ha. This is somewhat greater than what Ranney (1971) found for the basal area of 40-70 year old forest stand edges (i.e., 43.8 m^2/ha) and comparable to the basal area he found for greater than 70 year old stand edges (i.e., 67.4 m^2/ha). Basal area distribution among DBH classes (Figure 5.3) showed that trees in the 30-40 cm size class were the primary contributors to the sampled mesic stand's overall basal area. The distribution also indicates that these are uneven-age stands. Figure 5.4 shows actual stand density (as opposed to relative) by DBH class. This distribution, which was smoothed, was similar in appearance to that found by Ranney (1978) for 40-70 year old stand edges, except for the largest diameter class where the density in his stands appeared somewhat higher. Ranney (1978) stated that the "bulge" in the middle of the curve may indicate an overstory-understory interaction that is more common to cantilevered edges. That is, intermediate diameter age classes are able to successfully compete with the overstory as a result of this edge form's permitting additional light exposure.

5.2.2 Riparian Shoreline Forest Stands

Sampled forest stands in the shoreline habitat contained only 16 canopy species with a predominance of *A. saccharinum* and *Platanus occidentalis* (Table 5.1). They were moderately similar in composition to regional bottomland stands (CC = 0.52) as reported by Smith et al. (1975) and to reservoir riparian stands (CC = 0.65) along Watts Bar shoreline as reported by Amundsen (1994). Similarity determination (CC) used taxonomic levels and growth form specifications defined by Amundsen (1994). These specifications included: (1) only tree-size (DBH $\geq$ 12.5 cm) taxa, (2) *Acer* identified by species; (3) *Quercus* identified by group (i.e., red and white) and (4) remaining taxa identified by genus.

This moderate similarity in sampled stands and those located on the same shoreline as reported by Amundsen may partially be attributable to position of sample area. Amundsen took transects perpendicular to the shoreline that were 20 meters or more in length. In this study, quadrats were located parallel to and within four meters of the shoreline. Restricted habitat conditions of the shoreline quadrats may have influenced the establishment of a slightly different assemblage of trees than that found in the inland transects. Conditions that may have differed include: (1) diminution of edge effect (e.g., lighting); (2) level of climatic disturbance; and (3) depth-to-pool incursion.

Similar to the riparian site criteria for this study, Amundsen also restricted his study sites to those that had estimated depth-to-pool incursions less than 0.5 m by establishing shoreline slope criteria. However, because inland points on the perpendicular transects were increasingly distant from the reservoir pool, the probability for subsurface lateral flow barriers at each point also increased. The result would be an increased possibility for greater variability in depths to saturated soils.

By far, the predominant species in the sampled stand canopies species was *A. saccharinum*. Other dominant species of in order of decreasing importance were *P. occidentalis*, *Betula nigra*, *L. stryaciflua*, and *Fraxinus pennsylvanica* (Table 5.1). All of these species have long been recognized for their contribution to riverine and reservoir riparian and bottomland forest communities (Hall and Smith, 1955; Martin, 1971; Adams and Anderson, 1980; Huenneke, 1982; Amundsen, 1994).

Species-specific physiological adaptations to hydric conditions have been demonstrated for each of the dominants. For example, Hosner and Boyce (1962) showed that when seedlings of *A. saccharinum, P. occidentalis, F. pennsylvanica* and *L. stryaciflua* were saturated for up to 60 days, all but the latter formed adventitious roots. Hook and Brown (1973) demonstrated several mechanisms by which *P. occcidentalis, F. pennsylvanica,* and *L. stryaciflua* seedlings tolerated saturated soil conditions (e.g., accelerated anerobic respiration, secondary root development).

Results from laboratory and field studies indicate these dominant species' relative tolerances to saturation. When seedlings were saturated under laboratory conditions, tolerance occurred in the following order: *A. saccharinum* > *F. pennsylvanica* > *P. occidentalis* (Hosner, 1960); *F.*

pennsylvanica > *A. saccharinum* and *P. occidentalis* > *L. stryaciflua* (Hosner and Boyce, 1962) and *F. pennsylvanica* > *P. occidentalis* > *L. stryaciflua* (Hook and Brown, 1973). When inundated trees were observed in the field, tolerances were as follows: *Fraxinus* spp. > *L. stryaciflua* > *P. occidentalis* > *B. nigra* (Hall and Smith, 1955).

A. saccharinum and *P. occidentalis*, the stand codominants, are categorized as "tolerant" to inundated conditions (i.e., trees can withstand flooding for most of one growing season) using the U.S. Fish and Wildlife Species Tolerance Lists (Teskey and Hinckley, 1977B). Each of the five predominant species are identified in the National Wetland Lists as FACW (i.e., 67-99% probability of occurrence in wetlands) except for *L. stryaciflua* which was identified as FAC+ (i.e., 34-66% probability of occurrence in wetlands)(Table 2.2). Loy (1994) classifies each of these species as "most tolerant" to the riparian conditions along Watts Bar Reservoir (Table 2.2).

Dominant subcanopy species identified in the riparian shoreline habitat by relative density were *Alnus serrulata, Ligustrum sinense, Cornus amomum,* and *A. saccharinum* (Table 5.2). Dominant species identified from the m^2 samples were *L. sinense, Rhus radicans, Lonicera japonica,* and *A. serrulata* (see Table 5.3). The latter four species were also present in a relatively higher frequency of riparian quadrats than other species of this stratum (Table 5.4).

Species composition of the sampled stands may have also been influenced by their position along the shoreline edge. Canopy trees in sample quadrats that are also recognized as shade intolerant include *B. nigra, L. styraciflua* and *Salix nigra* (McKnight et al., 1981). Edge species may also include early successional species or those more commonly found in disturbed areas (i.e., r-strategists) (Ranney, 1978). *L. sinense*, an introduced species, is an example of an r-strategist, preferring disturbed areas as well as moist to wet conditions (Wofford, 1989). These preferences may explain its dominance in both the subcanopy and low-profile strata. Species that tend to have good vegetative growth are also more common on edges (Wales, 1972) such as *R. radicans and L.*

japonica, two of the dominant species identified in the low-profile stratum (Table 5.4).

Similarity as measured by Sørenson CC in canopy and subcanopy species was 0.73 and in subcanopy and low-profile species was 0.59. These moderate to high CCs demonstrated that canopy species were successfully reproducing themselves. Compositional differences between strata were partially due to the presence of mesic-associated species, albeit in minimal numbers, in the canopy and low-profile strata. Microtopography (e.g., hummocks) may have allowed for the survival and growth of species found in the canopy stratum (e.g., *Juniperus virginiana*, *Pinus taeda)*. However, their absence in the lower canopies indicates their low reproductive success under riparian conditions. Species found in the low-profile stratum (*Carya* spp., *Quercus* spp.) may have had seeds that fortuitously landed at the "right" time and place to germinate. However, they are apparently unable to successfully compete developmentally with more hydrically-adapted species as shown by their absence in the subcanopy.

Species diversity in riparian quadrat canopies and subcanopies was not significantly different ($\alpha = 0.11$). Since diversity is a function of richness and evenness, these factors were evaluated to determine if either of these characteristics significantly differed between strata. Results showed a significant difference in richness ($\alpha = 0.02$) but not in evenness ($\alpha = 0.06$). Subcanopies were richer in species than the canopies; however, they were not significantly different in their species distribution.

A total of only 21 species were represented in the canopy and subcanopy strata (Table 5.5). Anaerobic soil conditions of these sites very likely contributed to the limited species richness by selecting against taxa that were physiologically less able to adapt under these conditions to survive, grow, and reproduce. A limited propagule source may have also led to restricted species richness. Nilsson et al. (1991) showed that pre-existing vegetation from the pre-impoundment riverine system was one of the most significant influences on reservoir shore species richness. Since the entire riverine riparian zone was abruptly and permanently inundated with the closing of the dam, propagule sources for Watts Bar Reservoir riparian vegetation are now primarily from upstream hydric habitats and margins of local ponds and swamps.

Mean basal area for riparian quadrat canopy species was 67.7 m^2/ha. This is approximately 1.5 times greater than what Ranney (1978) found for the basal area of 40-70 year old mesic forest stand edges (i.e., 43.8 m^2/ha) and comparable to the basal area he found for greater than 70 year old mesic stand edges (i.e., 67.4 m^2/ha). It is approximately 3.5 times that of the mean basal area identified for the Watts Bar riparian shoreline reported by Amundsen (1994).

This remarkable difference between the basal area of sampled stands and those described by Amundsen along the Watts Bar Reservoir may be explained by one or more factors: (1) Site selection criteria for this study included a shoreline with a mature, all-age stand with a healthy canopy which resulted in well-stocked quadrats; (2) physical conditions (e.g., light and moisture) along the shoreline where quadrats were located may allow for better growth of species found in the Watts Bar riparian habitat than conditions inland from the shoreline where Amundsen's transects were located (i.e., normal to the shoreline); and (3) quadrat stands often contained species leaning over the water. These trees were measured at DBH and were included in the total basal area because of their biological productivity. However, their outward-extending position provided a gap in the quadrat, for additional woody species to fill.

Basal area distribution among DBH classes (Figure 5.3) showed that trees in the 20-30 cm size class are the primary contributors to the sampled riparian stand's overall basal area. Basal area distribution also indicates that these are uneven-age stands. Figure 5.4 shows actual stand density (as opposed to relative) by DBH class. As in the mesic habitat stands, this "bulge" in the middle of the stand density curve may indicate the intermediate diameter classes ability to successfully compete with the overstory as a result of the additional light exposure allowed by the cantilever edge form

(Ranney, 1978).

5.2.3 Comparisons between Mesic and Riparian Shoreline Forest Stands

This subsection compares strata composition and stand structure of mesic and riparian habitat stands. It also classifies canopy data and describes its apparent relationship to a hydric gradient.

5.2.3.1 Strata Composition and Stand Structure

<u>Canopy Stratum</u>

Similarity of canopy species in the mesic and riparian habitat stands was low, with a CC of 0.33. Only nine species were common to both habitats. Their hydric habitat preferences are described using their National Wetland List designations (Table 2.2). *Robinia pseudocacia* (UPL), *Celtis* spp. (FACU) and *J. virginiana* (FACU-) tend to occur more in uplands; *A. rubrum* (FAC), *P. taeda* (FAC), *Diospyros virginiana* (FAC), and *L. stryaciflua* (FAC+) have about an equal probability of occurring in wetland and nonwetland habitats; and *P. occidentalis* (FACW-) and *A. negundo* (FACW) tend to occur more in wetland than upland habitats.

Competitive abilities among species have been related to their presence in more than one habitat (i.e., β-niche breadth) (Pickett and Bazzaz, 1978). "Generalists," those with broader niche breadth, have been found to be poorer competitors than "specialists," species that dominate a single habitat (Adams and Anderson, 1980). Canopy species from the sampled stands appear to corroborate this theory. Trees common to both the mesic and riparian shoreline habitats, "generalists" were found to have lower IVs than the dominant species restricted to a single habitat, "specialists" (e.g., *A. saccharinum, Q. rubra)* (Table 5.1). The only exception to this was *P. occidentalis* which was common to both habitats and was a codominant in the riparian habitat.

Diversity in the canopy species of the mesic stands significantly differed from those in the riparian stands ($\alpha = 0.005$). Further investigation of the variables in this index showed that the mesic canopies were significantly richer in species ($\alpha = 0.01$), but did not show a significant difference in how species were distributed among quadrats ($\alpha = 0.06$). This indicates that the difference in species diversity in the habitat arboreal communities was primarily due to a difference in richness and, less so, in evenness. Findings of significantly greater diversity and richness in the mesic community than in the riparian are consistent with those of Frye and Quinn (1979), Bell (1980) and Adams and Anderson (1980).

Subcanopy Stratum

Similarity in the mesic and riparian stands' subcanopies (Table 5.2) was approximately equal (CC = 0.34) to that in the canopies. As in the canopy stratum, the subcanopy stratum of the riparian and mesic habitat stands had only nine species in common, although those they had in common varied slightly from the canopy comparison.

Diversity in the subcanopy species of the mesic stands significantly differed from the diversity of those in the riparian stands ($\alpha = 0.003$). Richness ($\alpha = 0.009$) and evenness ($\alpha = 0.01$) of the two habitat stands were also shown to significantly differ. There were approximately twice as many species in the subcanopies of the mesic stands as there were in the riparian stands. However, subcanopy species in the latter were more evenly distributed than those in the former.

Low-Profile Stratum

The low-profile stratum of the two habitats had many more species in common than was found in the canopy and subcanopy strata comparisons. A comparison of species found in the m^2 samples in the two habitat stands (Table 5.3) resulted in a CC of 0.52, while a comparison of the species that were present over the 100 m^2 quadrat (Table 5.4) resulted in a CC of 0.64. There was also no significant difference in the number of sapling, shrub and liana species between the two habitats when m^2 data ($\alpha = 0.55$) and presence data ($\alpha = 0.19$) were compared.

Species that increased similarity included saplings that were found in both habitats that were more commonly associated with the other habitat (e.g., red and white oaks in the riparian habitat and *A. saccharinum* in the mesic habitat). In addition, there were several lianas that were common to both habitats including *L. japonica, R. radicans and Vitis* spp.

Frye and Quinn (1979) found *L. japonica* and *R. radicans* to be more prevalent in the "high" than the "low" areas. However, in this study these vines were predominant in both habitats (Table 5.3). This may indicate that their wide distribution is as much or more attributable to their good vegetative growth under increased solar radiation (i.e., edge effects) and their tendency to invade hydrodynamically-disturbed areas as to any particular hydric amplitudes (Wales, 1972; Wofford, 1989).

Stand Structure

A comparison in bole basal area (m^2/ha) of sample riparian and mesic habitat stands did not demonstrate any significant difference ($\alpha = 0.42$). Bole basal area is used in species-specific logarithmic regressions to estimate above ground standing biomass and therefore is an indicator of productivity (Smith et al., 1975; Waring and Schlesinger, 1985). Sampled riparian stands may reasonably be assumed to have established along the cleared edge at about the time Watts Bar Dam closed in 1942. Since mesic stands were selected to be at least equivalent in age or greater, it appears that over the last 50 years basal areas of the sampled riparian stands are approaching that of their mesic shoreline counterparts.

A comparison of other structural measurements was also conducted. Although there was no significant difference ($\alpha = 0.31$) in the number of trees between quadrats in the mesic and riparian habitats, there was a significant difference in the number of poles ($\alpha = 0.02$). The riparian habitat stands had a much denser understory, particularly noted when setting up the quadrats in the field. The understory was often composed of *L. sinense, A. serrulata* and *C. amomum.* Edge closure was also shown to significantly differ between habitats ($\alpha = 0.001$). The three species that were common to the riparian understory generally created a dense curtain-like cover, with bowed branches dipping into the pool edge. This subcanopy edge form was similar to that described by Wales (1972) in his study of forest edges.

Canopy height ($\alpha = 0.001$) and closure ($\alpha = 0.001$) also significantly differed between habitat stands. Canopies of the stands in the mesic habitat were higher and more closed than those in the riparian habitat. Waterlogging of soil retards the growth of many species (Kozlowski, 1984) and may have contributed to the riparian species' reduced stature. However, height growth of some flood-tolerant species also increases under flooded conditions (Kozlowski, 1984). It is also possible that the reduced height could be the result of differences in the phenotype of the species, stand age or a strategic response in energy allocation in the root/shoot/crown ratio (Tilman, 1988). The latter response may also account for the increased litter fall reported by Amundsen (1994) (page 11 herein).

5.2.3.2 Canopy Composition Classification

TWINSPAN was applied to the 30 quadrat data matrix that contained importance values of 158 canopy species and pseudospecies. The resulting dendogram (Figure 5.5) identifies indicator species for the first two hierarchical levels. Appendix I contains the ordered two-way table also generated by TWINSPAN.

On the first division of the TWINSPAN dendogram, sampled stands in the mesic and riparian habitats were differentiated by their segregation into separate clusters (Figure 5.5). The only exception to this was a riparian quadrat (2R). TWINSPAN placed Quadrat 2R in the mesic cluster because it contained *A. rubrum*, a species that was only found in mesic quadrats. Further analysis of Quadrat 2R showed that it was primarily composed of *L. styraciflua* (Appendix F). Both *L. styraciflua* and *A. rubrum* have broad hydric amplitudes (Table 2.2) which may explain their

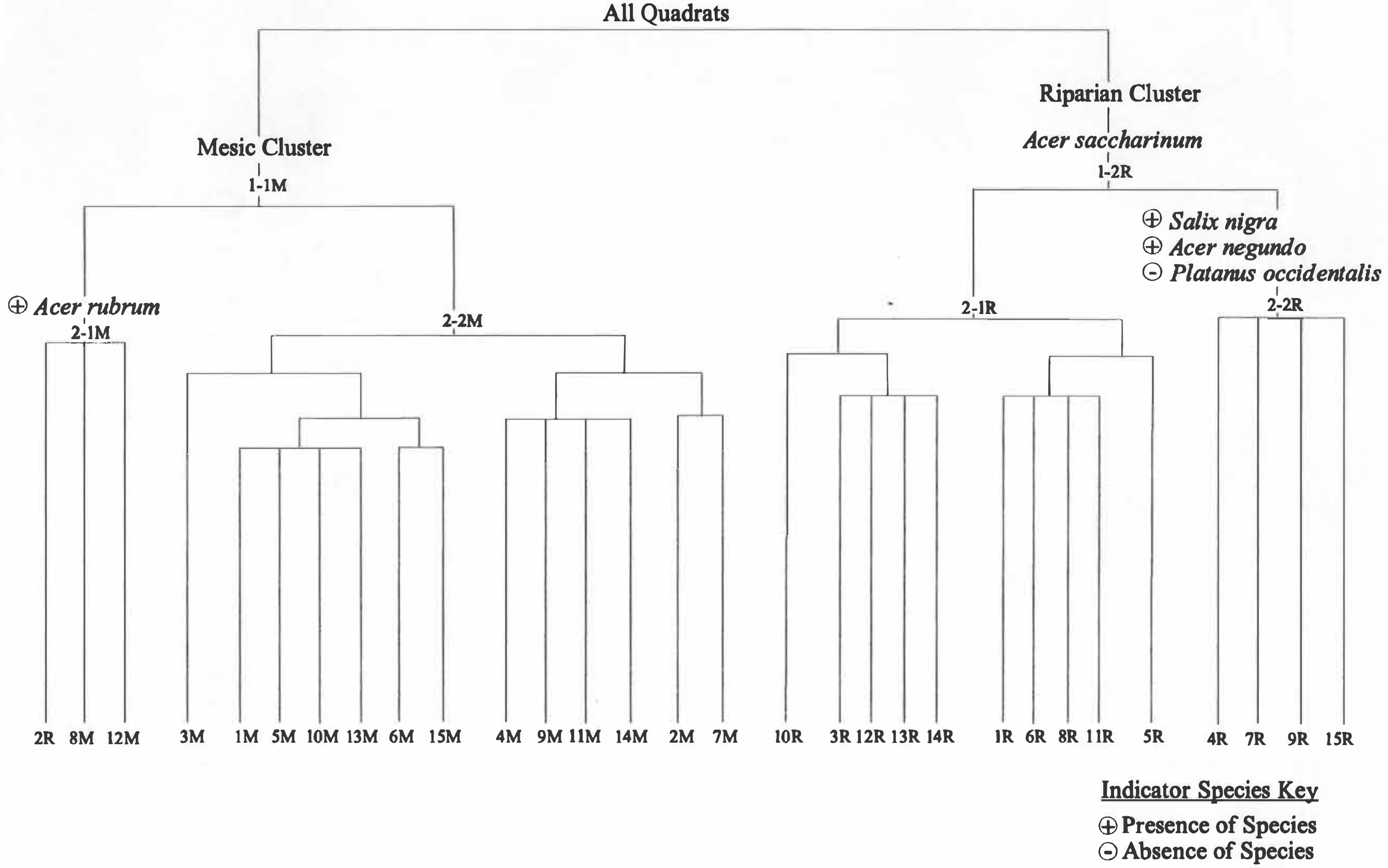


FIGURE 5.5 TWINSPAN classification of 30 quadrats using PC-ORD

presence in both habitats and, consequently, Quadrat 2R's compositional similarity to the mesic quadrats.

Indicator species are those that show the highest fidelity to a cluster (i.e., true to a single cluster) making them the best species to differentiate one cluster from another. Indicator species can also be used in the field to assign an unsampled stand to one of the clusters partitioned by TWINSPAN (Jongman et al., 1995).

TWINSPAN identified *A. saccharinum* as the indicator species on the first division (Figure 5.5). It was present in 14 out of the 15 riparian quadrats and was not found in the mesic quadrat habitat. If used for field purposes, an unsampled shoreline stand containing *A. saccharinum* would be assigned to the riparian cluster, indicating a riparian habitat. Conversely, a stand that did not contain this species would indicate a mesic habitat. Although *A. saccharinum* was selected as the best indicator species at this level, *Q. rubra* was present in 11 of the 15 mesic quadrats and may be as good an indicator of a mesic habitat (Appendix I).

On the second level of the dendogram under the mesic cluster (Figure 5.5), TWINSPAN identified *A. rubrum* as the indicator species because of its fidelity to cluster 2-1M. The species with the highest fidelity in cluster 2-2M was *Q. rubra*. An analysis of quadrat physical characteristics of the two mesic clusters (i.e., 2-1M and 2-2M) was conducted to determine whether any differences might explain this segregation of species. None were found.

On the second level of the dendogram under the riparian cluster (Figure 5.5), TWINSPAN identified *S. nigra, A. negundo* and *P. occidentalis* as the indicator species. *P. occidentalis* was found in eight of the 10 quadrats in cluster 2-1R. *S. nigra* was found in two and *A. negundo* was found in three of the four quadrats in cluster 2-2R (Appendix I). An explanation for species segregation between clusters was not found based on quadrat physical characteristics. However, in a study conducted by Hosner (1960), *S. nigra* and *A. negundo* were found to have a similar tolerance to flooding, which may also indicate similar hydric amplitudes.

5.2.3.3 Canopy Composition in Relation to an Environmental Gradient

Species Composition

Figure 5.6 presents the results of the DCA ordination analysis. DCA ordination axes represent hypothetical environmental gradients. Each point represents one of the 30 shoreline quadrats. The location of each quadrat is determined by a weighted average of the importance values of the species occurring within it. This weighting is based on the relative importance of each species.

Quadrat organization along the hypothetical gradients (i.e., axes) corresponds to the degree of change in species composition among the quadrats (i.e., "beta diversity"). The axes scales are in units of average standard deviations of species turnover multiplied by 100. The quadrats are organized along the axes so that the species they contain may optimally fit Gaussian response curves. The result is that species appear along an axis, ascend to their modes, and subside within approximately four standard deviations. Theoretically, quadrats spaced farther than four standard deviations apart contain no common species (Gauch, 1982).

Eigenvalues (i.e., λ_1 and λ_2) indicate how well each gradient (axis) explains the variation in species data. The eigenvalue in DCA ranges from 0 to 1. The more dispersed a distribution, the higher (i.e., the closer to 1) its eigenvalue. Axes 1 and 2 in Figure 5.6 had eigenvalues of 0.84 and 0.64 which are reflected in the relatively more dispersed distribution of quadrats along Axis 1 than 2.

The results of DCA showed a distinct segregation of mesic and riparian habitat quadrats along the first axis, indicating their compositional dissimarility (Figure 5.6). The riparian quadrat points are in a fairly tight cluster which suggests their compositional similiarity. The exceptions, Quadrat 10R (occurring midway on axis 1) and 2R (occurring in the mesic cluster) contain *L. styraciflua*. This species, also present in four mesic habitats, tends to have a fairly wide hydric amplitude (Hall and Smith, 1955).

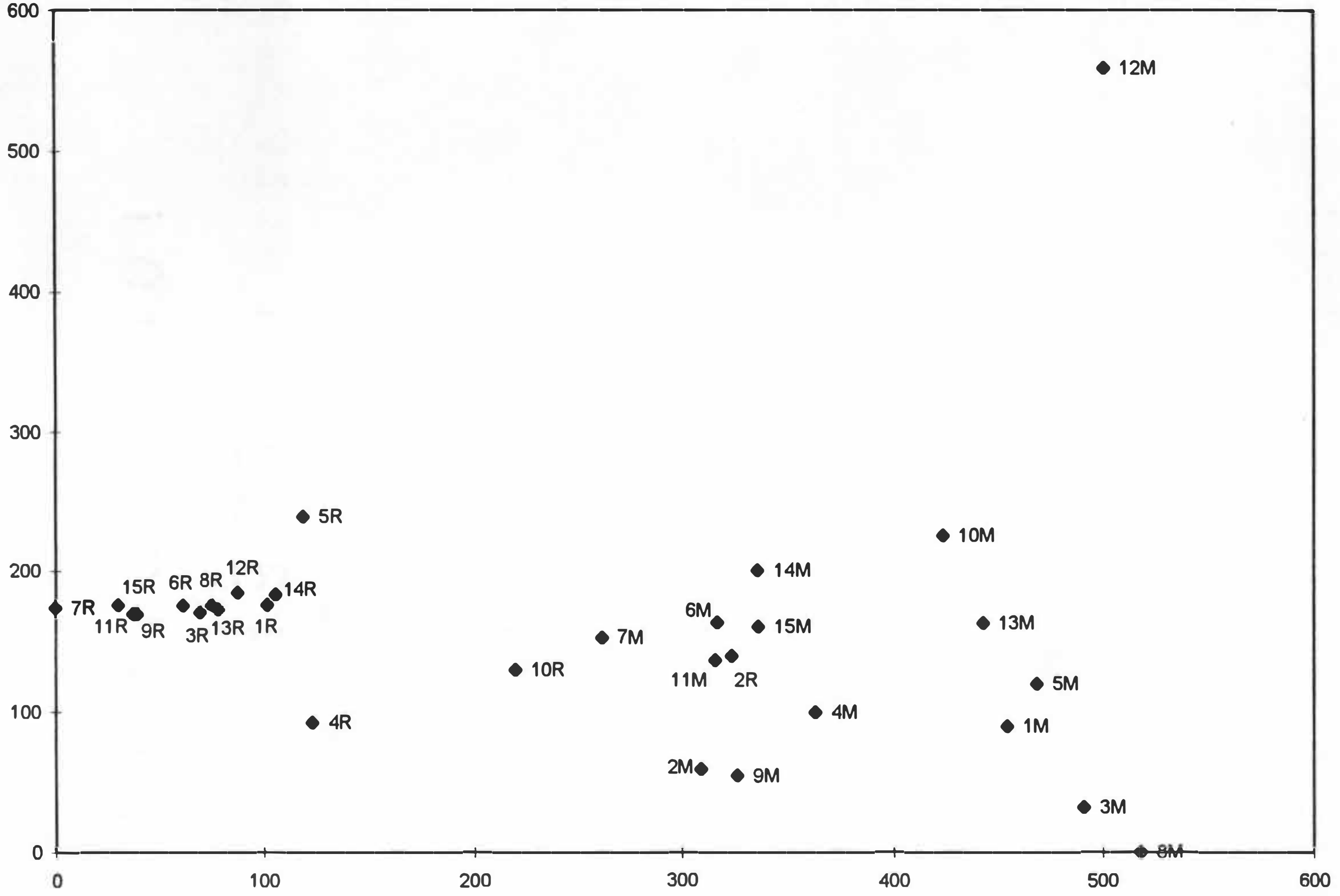


Figure 5.6 DCA Ordination of 30 Quadrats using PC-ORD

The mesic quadrat points are less tightly clustered than the riparian quadrats and more widely dispersed along Axis 2. This indicates that there is less intrahabitat species similarity among quadrats in the mesic than in the riparian habitats. Quadrat 12M, the mesic outlier, is composed of canopy species that are less common to the other mesic quadrats. For example, one of these species, *F. grandifolia*, is a very shade tolerant tree and is seldom found along forest edges (Ranney, 1978).

Axis Interpretations

Axis 1 of the DCA, the predominant underlying environmental gradient, appeared to be related to depth-to-pool incursion for two reasons. First, inspection of the ordination diagram showed that there was nearly a complete segregation of riparian (< 0.5 m depth-to-reservoir pool) from mesic (≥ 0.5 m) quadrats. Second, Pearson and Kendall tau-b's correlations between quadrats' species scores and depth-to-pool incursion estimates (Appendix C) were 0.67 and 0.48, respectively. Although moderate, these correlations do support the premise that species, at least among habitats, organized themselves along an apparent unsaturated soil depth gradient.

A subsequent analysis was then conducted to determine if the depth-to-pool gradient also appeared to influence the organization of species within a habitat. This analysis was conducted in two ways. First, depth-to-pool estimates were transcribed on the ordination field beside their respective quadrat points and visually inspected for trends within habitats (i.e., were riparian quadrat points clustered by shallow and deeper reservoir pool incursion depths?). None were observed. Second, DCA was applied to each set of habitat quadrats (i.e., 15 quadrats per matrix). Results of both ordinations indicated that variation in canopy species within a habitat was not explained by depth-to-pool incursion.

Two possible explanations for a lack of an observed gradient within the riparian habitat quadrats are as follows. First, for species to survive, grow and reproduce in the Watts Bar riparian habitat, they must also be able to adapt to changing saturation depths within 0.5 m from the soil surface as a result of the fluctuating reservoir pool levels. This adaptability would allow them to establish over a broader range of hydric conditions within the riparian habitat which would result in minimal species organization along a reservoir pool-influenced hydric gradient.

A second possible reason for this lack of an observed gradient is methodological. Depth-to-pool incursion was estimated based on (1) slope and scarp height geometry and (2) the assumption that the summer pool is maintained at 225.9 m msl. These estimates do not take into account summer pool level fluctuations (including mosquito control fluctuations), soil variability and subsurface barriers to reservoir pool incursion, all of which may reduce the accuracy of these estimates. As a result, minor calculated differences in depths among quadrats may actually be negligible.

The application of DCA to the mesic quadrats resulted in no discernable primary environmental gradients. One reason for a lack of an observed gradient related to depth-to-pool incursion quadrats seems apparent. By definition, mesic quadrats were outside the reservoir-imposed saturation zone by having a minimum unsaturated soil depth criteria of 0.5 m. The shallowest depth-to-pool estimate for a mesic quadrat was 1.9 m. The lack of any identifiable primary gradient may be due to the restricted environmental conditions imposed on these quadrats by shoreline selection criteria (e.g., pool edge location; < 50% slope), which resulted in limited sample area gradients.

6.0 SUMMARY AND CONCLUSIONS

6.1 Summary

Approximately fifty years ago, the landscape upslope from the natural, riverine position banks of the Tennessee River was inundated by the closing of Watts Bar Dam. Land primarily forested or farmed became a part of the newly formed shorelines. In low-lying areas that bordered the reservoir pool, TVA cleared much of the vegetation in preparation for the impoundment. Subject to the influence of the reservoir pool, riparian forests subsequently established in these new shore areas (Amundsen, 1994). The purpose of this study was to compare how edges of these riparian habitat forests located along Watts Bar Reservoir compositionally and structurally differed from mesic habitat forests that escaped sublateral pool flow influence by being topographically elevated.

Results showed that sampled mesic and riparian habitat stands were similar in productivity based on basal area (m^2/ha), but differed significantly in their structure and composition. Structurally, mesic stands were significantly taller, more closed in their canopy, and more open in understory and edge front than riparian stands. Riparian stands characteristically presented a dense curtain-like edge cover composed of three common understory species, *Cornus amomum, Alnus serrulata, and Ligustrum sinense.*

Compositionally, mesic stands exhibited characteristics of preimpoundment broadleaf mesic forests, while riparian stands resembled regional bottomland and previously examined Watts Bar Reservoir riparian forests. Stands in the mesic habitat contained 29 hardwood taxa with a predominance of oaks and hickories, while those in the riparian were limited to 16 taxa. Comparison of canopy species in the two habitats yielded a CC of 0.33. The mesic arboreal community was also significantly richer and more diverse than the riparian community.

TWINSPAN and DCA confirmed this taxal dissimilarity. The former partitioned mesic and riparian quadrats into two separate clusters. The latter segregated quadrats by habitat along a single environmental gradient. Subsequent statistical analyses and visual inspection of data in ordination space indicated that this gradient was related to its apparent soil saturation resulting from the reservoir pool incursion. However, no predominant environmental gradient was detected within either habitat.

6.2 Application

Results of this study further understanding of how reservoir shoreline conditions affect the composition and structure of shoreline forests and pinpoint types of additional shoreline ecological studies that are needed. The results may also prove useful to managing and conserving natural resources along reservoir shorelines in three ways. First, the study has demonstrated the importance of the relationship between shoreline geomorphology and its influence on established vegetation. This relationship should be incorporated into future shoreline inventories. Such inventories may benefit those who assess, monitor, and manage shoreline and aquatic fauna by providing more detailed habitat descriptions. They may also be useful to shoreline managers who monitor agricultural and pollutant run-off since the extent of vegetation density and cover along a shoreline affects surface water detention.

Second, the finding that productivity (as indicated by basal area) was approximately equal in sampled riparian and mesic shorelines reinforces the importance of nearshore habitat contribution to the allochonthous resource input required for sustaining reservoir aquatic life. Third, structural and compositional data provided by this research may assist the shoreline manager in better depicting the shoreline vegetation to the public. For example, as a result of TVA's emphasis on vegetation management in its Shoreline Development Initiative, shoreline residents have shown renewed interest in, and have asked numerous questions about, the shoreline vegetation landscape. Some of these questions may be better answered with this data.

6.3 Future Studies

Results of this study prompt the need for additional research in three areas. First, "edge effects" on the sampled stands were speculated to occur in this study based on their comparison with results from prior edge studies. However, it would be of interest to test these effects by analyzing forest composition and structure (including changes in shoot/root/foliage allocations) on perpendicular transects from the reservoir pool. Second, and a related issue, as shoreline development continues, forests are becoming increasingly fragmented. How is fragmentation affecting their overall composition and structure (i.e., as shoreline forests gain more "edges")? Third, observations were made of substantial erosion that has occurred along channel frontage containing mature, healthy and relatively undisturbed forest stands. How effective is vegetation in preventing erosion in areas that are severely impacted by waves, and at what point and under what conditions, is vegetation no longer sufficient to minimize shoreline loss?

6.4 Conclusion

In one-half century or less, a compositionally and structurally distinct forest community has established and succeeded along a reservoir-pool influenced shoreline. Habitats along the shoreline that escaped the influence of the reservoir pool contain forest stands similar to those described in the region prior to impoundment. A recognition of the differences and similarities in these two contrasting shoreline communities may benefit those charged with assessing, monitoring and managing reservoir shoreline resources and will hopefully be encompassed in future management plans.

LITERATURE

LITERATURE

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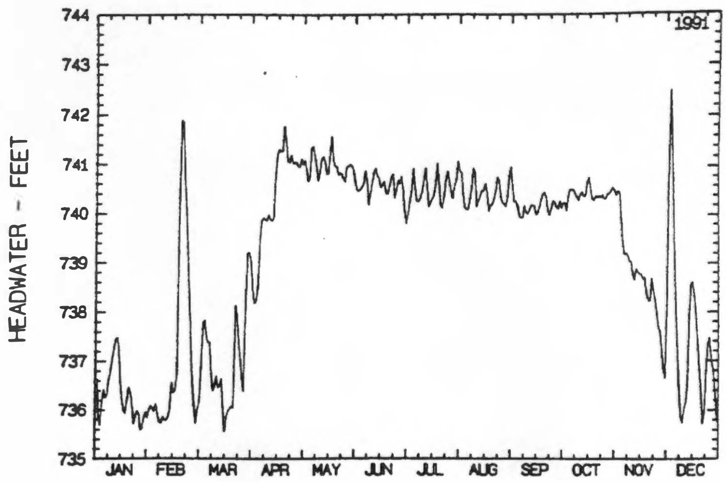
APPENDICES

Appendix A

Watts Bar Reservoir Operating Levels: Weekly Averages from 1991 through 1995


1991
HEADWATER - FEET
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737
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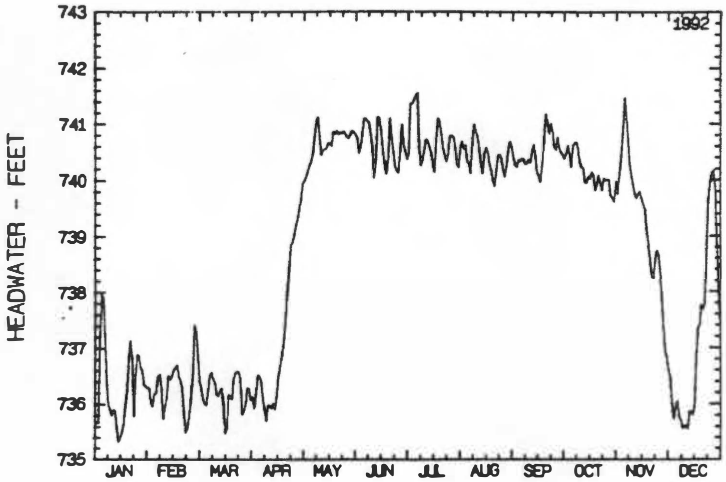
735
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC


1992
HEADWATER - FEET
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737
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735
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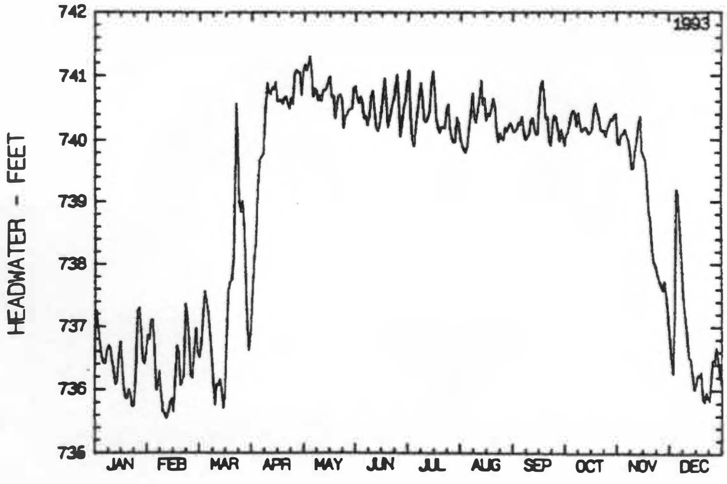
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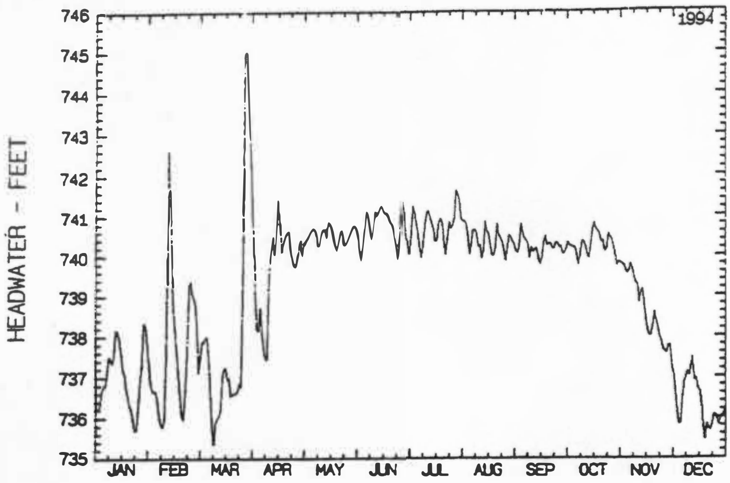
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC


1994
HEADWATER - FEET
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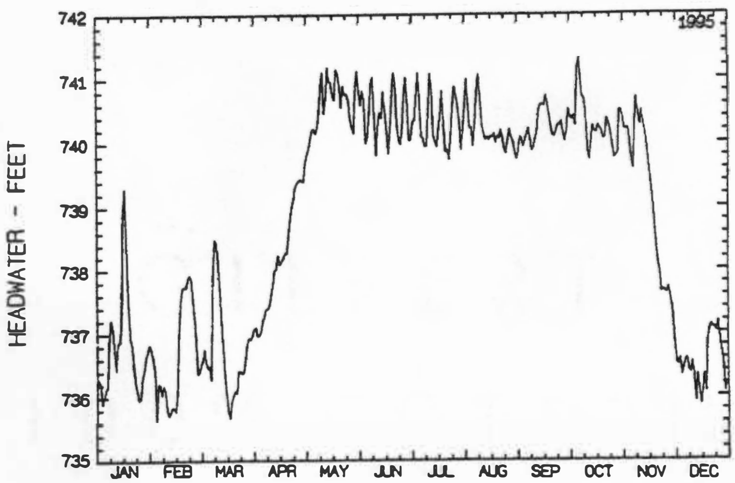
1995
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Appendix B
Shoreline Selection Criteria: Checklist of Habitat Disturbance Indicators

Disturbance Checklist: Site Disqualification Characteristics

Construction & Buildings

_____ Boat dock

_____ Riprap

_____ Contemporary residential or industrial

_____ Any impermeable surfaces

Miscellaneous Human Disturbance

_____ Trails: signs of clearing

_____ Signs of camping

_____ Logging: clearly cut stumps

Planting

_____ Pine stands

_____ Deciduous stands: ornamental or fruit

_____ Evenly spaced trees

Animals

_____ Accessibility to cattle, cattle paths to reservoir

_____ Heavily browsed vegetation

Physical

_____ Fire: fire scars; signs of charring

_____ Weather: signs of major wind damage; > 20% of stand windthrown

General Canopy Appearance

_____ >10% dead tops

_____ Highly uneven

Appendix C
Formula used to Estimate Depth-to-Reservoir Pool and its Geometric Derivation

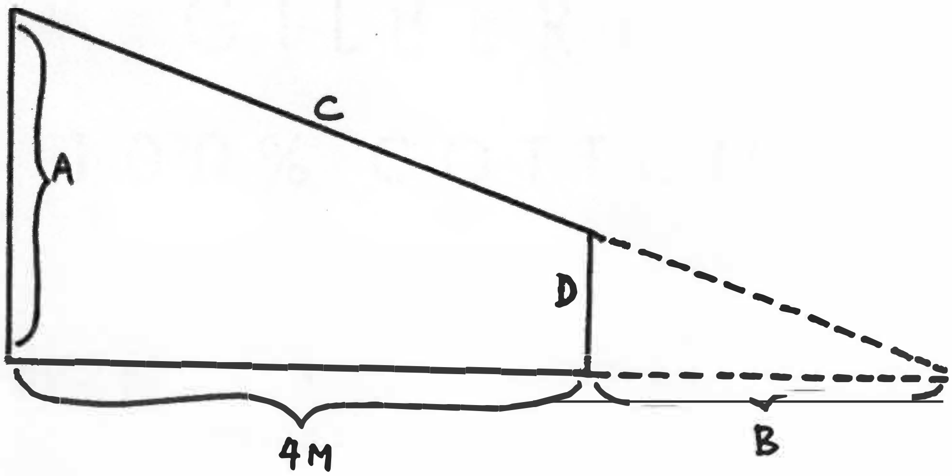
The depth-to-subsurface lateral pool inflow estimate was calculated four meters slopeward at the back edge of the quadrat. This calculation was based on the geometric configuration of the shoreline shown below in conjunction with the following formulas. For purposes of this calculation, the shoreline was hypothetically extended beyond the scarp, indicated by the dotted lines. Quadrat width was not corrected for slope.

$$A = (B + 4m) \times C$$

$$B = D/C$$

$$A = ([D/C] + 4\ m) \times C$$

A = Depth-to-pool estimate
B = Hypothetically extended shoreline
C = Quadrat slope percent divided by 100
D = Scarp height



Appendix D

Means, Ranges, and Standard Deviations of Slope and Scarp Height Measurements and Estimated Depth-to-Pool Incursion Calculations by Quadrat

	Slope (%)[1]			Scarp Height (m) [1,2]			Estimated Depth-to-Pool Incursion (m) [3]		
	Mean	Range	Std Dev.	Mean	Range	Std Dev.	Mean	Range	Std. Dev.
1M	23	20-26	3	1.93	1.76-3.01	0.79	2.83	1.66-3.85	0.79
2M	26	19-34	6	1.58	1.20-1.70	0.22	2.61	2.40-3.06	0.26
3M	20	14-30	7	1.83	1.75-2.00	0.10	2.64	2.39-2.95	0.21
4M	41	36-47	5	1.34	1.29-1.39	0.07	2.98	2.73-3.27	0.22
5M	22	20-25	2	1.19	1.00-1.25	0.10	2.08	2.00-2.17	0.06
6M	33	29-35	3	0.91	0.75-1.10	0.18	2.21	1.91-2.38	0.19
7M	36	35-40	2	0.50	0.50-0.50	0.00	1.95	1.90-2.10	0.08
8M	26	20-26	8	1.28	1.00-1.75	0.31	2.32	2.00-2.60	0.26
9M	27	17-39	9	2.31	1.70-3.70	0.88	3.39	2.38-4.98	0.99
10M	32	18-40	9	1.56	1.35-1.95	0.24	2.84	2.17-3.55	0.54
11M	48	40-50	3	1.04	1.00-1.10	0.05	2.94	2.82-3.00	0.08
12M	32	24-38	6	0.72	0.50-0.90	0.14	2.31	1.58-3.90	0.93
13M	23	18-25	3	1.47	1.15-1.80	0.29	2.39	2.15-2.66	0.23
14M	39	32-44	5	2.50	1.25-3.75	0.88	4.07	2.77-5.51	0.98
15M	47	45-50	2	1.16	1.0-1.25	0.02	3.05	2.84-3.25	0.16
1R	1	0-4	2	0.01	0.0-0.03	0.01	0.09	0.04-0.16	0.04
2R	0	0	0	0.34	0.25-0.42	0.06	0.34	0.25-0.41	0.05
3R	7	5-10	2	0.14	0.0-0.25	0.11	0.44	0.39-0.48	0.04
4R	4	0-9	4	0.02	0.00-0.11	0.05	0.19	0.00-0.36	0.13
5R	6	0-10	4	0.01	0.00-0.04	0.02	0.25	0.03-0.40	0.15
6R	0	0-0	0	0.02	0.00-0.03	0.01	0.03	0.03-0.03	0.00
7R	3	1-4	1	0.03	0.00-0.07	0.03	0.15	0.04-.25	0.08
8R	8	7-9	0	0.04	0.02-0.06	0.01	0.34	0.30-0.40	0.04
9R	1	0-6	3	0.08	0.03-0.10	0.06	0.13	0.06-.24	0.07
10R	4	3-5	0	0.00	0.00-0.00	0.00	0.16	0.12-0.20	0.03
11R	3	1-8	3	0.00	0.00-0.00	0.00	0.12	0.00-0.32	0.12
12R	6	5-6	0	0.16	0.00-0.20	0.08	0.39	0.24-0.44	0.09
13R	1	1-2	0	0.00	0.00-0.01	0.01	0.05	0.00-0.08	0.02
14R	5	5-6	0	0.06	0.04-0.11	0.03	0.27	0.24-0.31	0.03
15R	7	0-12	5	0.04	0.00-0.10	0.04	0.32	0.10-0.48	0.15

[1] Mean and range of five measurements taken within each quadrat. For additional information regarding methodology, see Section 4.0.

[2] Scarp height above normal summer pool (225.9m msl).

[3] Mean and range of results of five depth-to-pool incursion calculations conducted for each quadrat using the formula in Appendix C.

Appendix E
Quadrat Descriptions

ID#[1]	RMM[2]	Description
1M	TRM532.7R	Predominantly oak canopy with thick oak/hickory understory. Minimal ground cover. Soil is dark and loamy. No signs of disturbance - no jetsam. Scarp generally vertical to concave in form, with ≈20% of scarp eroded back to bedrock at 225.9 m msl pool. Sparse woody vegetation (e.g., alder) at scarp base. Minimal obstruction of reservoir view by edge vegetation.
2 M	TRM547G	Predominantly sweetgum and tulip poplar canopy. Numerous blackberry bushes and poison ivy prolific on ground and up trees. At various points within 1 m of pool edge terrain felt unstable - could feel ground vibrations when walking. Also ground "pocketed" as if there was subsurface collapsing. Minimal jetsam. Noticable walking path, however minimal vegetation damage. Scarp moderately concave, some sloughing and terracing.
3M	TRM549R	Predominantly oak canopy. Fairly open understory and minimal ground cover. Drier site, more cedars and pine. Scarp ranged from concave to sloughing and terracing. Moderately vegetated scarp including grasses & low-profile vegetation. Large tree (40+ cm DBH) uprooted and laying parallel to shoreline, did not appear to be from quadrat.
4M	TRM549.6G	Predominantly oak canopy with open oak hickory understory. Ground cover primarily honeysuckle. Scarp generally concave. Several terraced points jutting out from edge that appear to be stabilized by trees. Adjacent scarp eroded back with 7 root-exposed trees at edge tilting over pool.
5M	TRM557.5G	Predominantly oaks canopy. Open understory with healthy stand of poison ivy ground cover with vines on nearly every tree. Minimal observed jetsam. Downstream of quadrat (≈50 m), boards nailed to tree (old campsite?). Upslope of quadrat 1935 TVA concrete marker. Scarp primarily concave with vegetation overhang and minimal cover.
6M	CRM3.5G	Located on Kingston Steam Plant properties. Site appears undisturbed. Cornfield located ≈ 60 m behind quadrat. Predominantly slippery elm and oak canopy with elm and hornbeam understory. Concave scarp with minimal vegetation cover and root overhang.
7M	CRM5.0R	Predominantly tulip poplar canopy with flowering dogwood and redbud understory. Scarp ≈ 0.5 m, lowest of all mesic quadrats. Mean slope ≈ 36%. Scarp and into quadrat ≈ 0.25 m covered in alder, resulting in dense edge cover. Pool edge shallow. Scattered flotsam.

ID#[1]	RMM[2]	Description
8M	ERM4.25G	Located just inside curvature of inlet, however open to main channel. Predominantly oak canopy with sparse understory. Only site with cucumber magnolia. Moderate groundcover. Minimal signs of disturbance, no observed jetsam. Scarp terraced in several areas, covered in grasses with several poles and trees.
9M	TRM571.2R	Predominantly oak and shagbark hickory canopy. Contained yellow chestnut oak with 71.5 cm DBH. Overall very high density of trees and fairly open understory. Sections of scarp bound in roots with remaining areas sloughing. Slough slope covered predominantly in woody vines and poles.
10M	TRM574.2G	Predominantly oak canopy with hop hornbeam subcanopy. Contained red oak with 70.0 cm DBH. Fairly vertical scarp. Several large dead trees in pool parallel to quadrat edge that appear to be from former scarp edge. View of pool minimally obstructed by edge vegetation.
11M	TRM574.8G	Predominantly oak canopy. Trees heavily covered in honeysuckle and poison ivy vines. Steepest quadrat with mean slope of 47%. Large rocks found throughout and around quadrat, indicating prior upslope instability. Scarp nearly vertical. Seven trees tilting over pool. No observed jetsam.
12M	TRM575.9G	Located just inside curvature of Little Paint Rock inlet. Predominantly hickory canopy with fairly open understory. Wildflowers prevalent. Minimal obstruction pool view by edge vegetation. Scarp generally concave with root-mat overhang and several trees leaning over pool. Extended point on edge being held by dead tree roots. 20 m upslope from quadrat, old bobwire fence, however no noted contemporary disturbance within quadrat.
13M	TRM575.9G	Predominantly oak canopy with fairly open understory. View of pool minimally obstructed by edge vegetation. Wildflowers prevalent, minimal vines. Several dead black locust trees leaning over water's edge. Scarp primarily concave. No observed jetsam. Immediately upslope of quadrats 12 M and 13 M which were in proximity of one another, mix of oaks/hickories, 50+ cm DBHs.
14M	TRM576.7G	Predominantly oak and hop hornbeam canopy with a hop hornbeam understory. Several large branches fallen into quadrat from downed upslope trees which may have occurred from tornado in '93. Quadrat located near tornadeo path, but no observed tree damage in quadrat. Scarp forms variable including vertical, concave and sloughing.

ID#[1]	RMM[2]	Description
15M	TRM577.6G	Contained basswood with 2 primary boles (DBH= 44 and 48) and numerous base sprouts - most most important in quadrat. Understory relatively dense. Contained extensive bush-size bladdernut. Front edge partially terraced with established vegetation, ranging from herbacous cover to poles. Portion of edge eroded back to bedrock. On rock outcropping, species more commonly associated with riparian habitat found.
1R	TRM533R	Predominantly sycamore canopy. Both canopy and subcanopy fairly open. *Amorpha* spp. prevalent. Groundcover primarily grasses (e.g., *Uniola* spp.) and dayflower (*Commelina* spp.). Soil had sandy loam texture. Slight curvature in shoreline of quadrat, catching woody debris and flotsam washup. ≈ 65% of front edge covered in alder and silky cornel. Area behind quadrat low-lying with willows.
2R	TRM536.5G	Predominantly sweetgum canopy with alder and red maple understory. ≈20% of quadrat ground covered in *Uniola* spp. grass. Per adjacent land owner, area is designated as "bird-sanctuary." Identified by TVA on land-use maps as "marginal strip." Dense subcanopy pool-edge coverage composed primarily of alder and silky cornel. Soil had sandy loam texture. Minimal flotsam.
3R	TRM538.4G	Canopy contained only silver maple and green ash. ≈ 40% of understory fairly open, while remainder was primarily dense alder and silky cornel. Quadrat contained downed branches from apparent wind-damage, however quadrat canopy met disturbance criteria. Soil had sandy loam texture. Moderate to heavy flotsam.
4R	TRM557.5R	Located on channel-side of winter peninsula/summer island. On day of sampling with water level at ≈ 740 ft msl, channel on backside of "island" was partially impassable by kayak due to shallowness. Quadrat predominantly *Celtis* spp. Front-edge coverage primarily in alder and privet. Moderate to heavy flotsam.
5R	ERM4.2G	Predominantly silver maple canopy. Only quadrat with loblolly pines (two @ ≈ 22 cm DBH each). ≈ 60% of front edge composed of silky cornel and alder, both covered in honeysuckle. Slight swale in quadrat which caught flotsam.
6R	TRM573.8G	Primarily silver maple canopy. Honey suckle-covered silky cornel understory in ≈ 50% of quadrat. Remainder more open with waist-high poison-ivy ground-cover and vines covering tree trunks. Moderate flotsam.

ID#[1]	RMM[2]	Description
7R	TRM575R	Canopy contained only silver maple and willow with moderately dense privet understory covered in trumpetvine and clematis. Curvature in shoreline edge with depression extending through quadrat and containing debris build-up (e.g., various flotsam, construction materials, tire, organic debris) . Located near mouth of Paint Rock Creek inlet. Scarp bottom scoured at 2 of 5 measured points with total scarp height equal to ≈0.3 m.
8R	TRM577.2G	Predominantly silver maple and sycamore canopy. Primarily silky cornel and privet in front 2 m of quadrat, back 2 m understory opens up. Minimal disturbance. Sandy loam soil texture. ≈ 30+ m upslope from quadrat, slope increased to ≈ 25% to level area that had appearance of old road.
9R	TRM579.4G	Predominantly silver maple canopy and very dense understory of privet. Appears that there may have been some clearing behind quadrat as indicated by tree form. No signs of vegetation disturbance (e.g., stumps) inside quadrat. Undercutting of scarp extensive at couple of edge points. Overhang composed of silver maple root mass.
10R	TRM580G	Predominantly slippery elm and sweetgum canopy with primarily silver maple and slippery elm understory. Quadrat on slight inward curve that caught notable amounts of flotsam (e.g., woody debis). Included logs etc. positioned parallel to edge that may provided some shoreline protection from waves. Fairly shallow waters in front of quadrat. ≈ 40% of front edge fairly open with canary grass and blackberry bushes covered in clematis. Remainder mostly tree-lined. View of pool only moderately obstructed by edge vegetation.
11R	TRM581.4G	Predominantly silver maple canopy with extremely thick understory covered in masses of various vines. Front edge primarily silky cornel. Moderate to heavy flotsam throughout quadrat. Fairly shallow waters in front of quadrat with offshore emergents including four buttonbushes.
12R	TRM582.1G	Predominantly river birch canopy and privet and alder understory that also created dense edge cover. Outside, but near upstream end of quadrat, old stonewall jutting out into pool normal to shoreline. Day of sampling with pool at ≈ 741 ft msl, 40% of quadrat floor covered in water (1-3").
13R	TRM583.3G	Predominantly willow and sycamore canopy with alder understory. Edge highly feathered with extended points held by alder clumps. Scarp bottom scoured at 4 of 5 measured edge points. Scarp height of these points ranged from 0.3 to 1 m below 741 ft msl level with edge undercut extending up to 1 m.

ID#[1]	RMM[2]	Description
14R	TRM584.8R	Predominantly sycamore and river birch canopy and an extremely dense understory composed primarily of vine-covered privet. Quadrat located at shoreline point. Scarp bottom scoured at base. Below 741 ft msl scarp extended ≈ 0.25-0.5 m. ≈10% of canopy at end of point appeared to be wind-damaged.
15R	TRM588.4R	Located on penninsula. Predominantly a dense silver maple canopy. Fairly open understory with grass and vine ground cover except for ≈ 20% of quadrat containing pawpaws poles. Scarp concave with moderate undercutting (e.g., ≈ 0.2 m) of front edge trees. Six to eight trees tilting over pool.

[1] "R" after quadrat number indicates its location in a riparian habitat and "M" its location in a mesic habitat.
[2] RMM = river mile marker. "R" after river mile number indicates "river right" side of channel which is the right side of the channel when going upstream. Conversely, "G" indicates "river left" which is the left side of the channel when going upstream.

Appendix F
Canopy Species Importance Values 200 by Quadrat

Mesic Quadrats

Canopy Species	1M	2M	3M	4M	5M	6M	7M	8M	9M	10M	11M	12M	13M	14M	15M
Acer negundo											9.15				
Acer rubrum								14.40				50.54			
Aesculus flava									10.03						
Carya cordiformis							14.74								
Carya glabra										25.08		111.68			
Carya ovata									70.02						
Carya tomentosa			17.63					40.65							
Celtis spp.		14.21							8.38						
Cercis canadensis		8.83													
Diospyros virginiana							28.58								
Fagus grandifolia			11.73									37.77			
Fraxinus americana				36.37		9.16	31.96				30.36				
Junipersus virginiana	30.45				55.57	11.09	16.32			28.87			51.59		
Liquidambar styraciflua		83.96	17.22			37.92		29.72							
Liriodendrum tulipifera	37.73	65.23					72.89		18.02	20.13					25.06
Magnolia acuminata								42.66							
Ostrya virginiana						24.61				40.39				52.35	
Oxydendrum arboreum				16.28											
Pinus taeda														17.09	
Pinus virginiana			54.31		21.71										
Platanus occidentalis							35.51				22.91			17.09	
Prunus serotina						29.65									
Quercus alba			59.65	53.34											
Quercus falcata						9.88									
Quercus marilandica	39.51				22.50			72.57							
Quercus muehlenbergii			13.97	22.82					50.15		42.76				

Mesic Quadrats (continued)

Canopy Species	1M	2M	3M	4M	5M	6M	7M	8M	9M	10M	11M	12M	13M	14M	15M
Quercus rubra	74.47		11.73	48.72	100.2	23.44			9.88	85.53	83.82		148.41	69.23	36.76
Quercus stellata	17.84		13.77												
Robinia pseudocacia		27.77		11.99					33.52		11.01			44.23	
Tilia americana															100.11
Ulmus rubra				10.48		54.25									38.07

Riparian Quadrats

Canopy Species	1R	2R	3R	4R	5R	6R	7R	8R	9R	10R	11R	12R	13R	14R	15R
Acer negundo				10.28					34.39						21.14
Acer rubrum		37.59			26.45										
Acer saccharinum	14.66		137.48	58.67	68.80	126.45	147.91	97.92	135.88	24.38	148.54	47.47	33.26	15.12	119.31
Betula nigra				102.70	30.54				29.73	16.60	13.05	110.82	18.82	65.97	
Celtis spp.															
Diospyros virgniana		24.44													
Fraxinus pennsylvanica			62.52							24.76		41.70	30.13	17.54	18.84
Juniperus virginiana													9.43		
Liquidambar styraciflua		137.97								66.28					
Morus rubra	15.25														
Pinus taeda					37.19										
Platanus occidentalis	170.09			10.77	37.01	49.25		90.67			26.49		50.24	101.37	13.90
Robinia pseudocacia				17.58											
Salix nigra							52.09						58.12		26.81
Ulmus rubra						24.30		11.41		67.99					

Appendix G
Woody Flora Species Listing: Identified by Growth Form and Habitat Occurrence

Scientific Name	Common Name	Growth Form & Habitat occurrence[1]
Acer negundo	Boxelder	T-m; P-m; S-m; T-r; P-r; S-r
Acer rubrum	Red Maple	T-r; P-r; S-r; T-m; P-m; S-m
Acer saccharum	Sugar Maple	P-m; S-m; S-r
Acer saccharinum	Silver Maple	T-r; P-r; S-r; S-m
Aesculus flava	Yellow Buckeye	T-m; S-m
Albizia julibrissin	Mimosa	P-m
Alnus serrulata	Smooth Alder	P-r; B-r; P-m, B-m
Amelanchier spp.	Serviceberry, Shadbush	B-m
Amorpha fruticosa	Amorpha	P-r; B-r; B-m
Anistichus capreolata	Cross Vine	V-r; V-m
Asimina triloba	PawPaw	P-m; P-r; S-m; S-r
Betula nigra	River Birch	T-r; P-r; S-r
Campsis radicans	Trumpet Vine	V-m; V-r
Carya cordiformis	Bitternut Hickory	T-m; P-m
Carya glabra	Pignut Hickory	T-m; P-m
Carya ovata	Shagbark Hickory	T-m; P-m
Carya tomentosa	Mockernut Hickory	T-m; P-m
Carya spp.	Hickory Sapling	S-m; S-r
Celtis spp.	Hackberry/Sugarberry	T-m; S-m;T-r; P-r; S-r
Cephalanthus occidentalis	Buttonbush	B-r
Cercis canadensis	Redbud	T-m; S-m; P-m; S-r
Clematis terniflora	Clematis	V-m; V-r
Cocculus carolinus	Coralbeads	V-r
Cornus amomum	Silky Cornel	P-m; P-r; B-r
Cornus florida	Flowering Dogwood	P-m; S-m
Dioscorea villosa	Wild Yam	V-m
Diospyros virginiana	Persimmon	T-m; P-m; T-r; S-r
Fagus grandifolia	American Beech	T-m; P-m; S-m
Fraxinus americana	American Ash	T-m
Fraxinus pennsylvanica	Green Ash	T-r; P-r
Fraxinus spp.	Ash	S-m; S-r
Halesia carolina	Silverbell	P-m
Hydrangea spp.	Hydrangea	B-m
Itea virginica	Virginia Willow	B-r
Juglans nigra	Black Walnut	S-r
Juniperus virginiana	Eastern Red Cedar	T-m; P-m; S-m; T-r; S-r
Ligustrum sinense	Privet	B-m; P-r; B-r

Scientific Name	Common Name	Growth Form & Habitat occurrence[1]
Liquidambar styraciflua	Sweetgum	T-m; P-m; S-m; T-r; P-r; S-r
Liriodendrum tulipifera	Tulip Poplar	T-m; S-r
Lonicera japonica	Honeysuckle	V-m; V-r
Magnolia acuminata	Cucumber Magnolia	T-m
Morus rubra	Red Mulberry	T-r; P-r
Morus spp.	Mulberry	S-r
Nyssa sylvatica	Black Gum	P-m
Ostrya virginiana	Hop Hornbeam	T-m; S-m; P-m
Oxydendrum arboreum	Sourwood	T-m; S-m
Parthenocissus quinquefolia	Virginia Creeper	V-m
Pinus echinata	Shortleaf Pine	P-m; S-m
Pinus taeda	Loblolly Pine	T-m; T-r;
Pinus virginiana	Virginia Pine	T-m; P-m; S-m; P-r
Platanus occidentalis	Eastern Sycamore	T-m; T-r; P-r; S-r
Prunus serotina	Black Cherry	T-m; P-m; S-m; S-r
Quercus alba	White Oak	T-m; P-m
Quercus falcata	Southern Red Oak	T-m
Quercus marilandica	Blackjack Oak	T-m; P-m; S-m
Quercus muehlenbergii	Yellow Chestnut Oak	T-m; P-m
Quercus phellos	Willow Oak	P-m; S-m; P-r; S-r
Quercus rubra	Red Oak	T-m; P-m
Quercus stellata	Post Oak	T-m
Quercus spp.	Oak Group: Bristle-Tipped[2]	S-m; S-r
Quercus spp.	Oak Group: Wavy- Edged[2]	S-r; S-m
Quercus spp.	Oak Group: Feather-Lobed[2]	S-m
Rhus radicans	Poison Ivy	V-m; V-r
Robinia pseudocacia	Black Locust	T-r; T-m; P-m; S-m; S-r
Rosa palustris	Swamp Rose	B-r
Rubus spp.	Raspberry, Dewberry, Blackberry	B-m; B-r
Salix nigra	Black Willow	T-r; P-r; S-r
Sassafras albidum	Sassafras	P-m; S-m
Smilax bona-nox	Greenbrier, Catbrier	V-m; V-r
Smilax glauca	Greenbrier, Catbrier	V-r
Smilax spp.	Greenbrier, Catbrier	V-m; V-r
Staphylea trifolia	Bladdernut	P-m; B-m; B-r
Tilia americana	American Basswood	T-m; P-m; S-m

Scientific Name	Common Name	Growth Form & Habitat occurrence[1]
Ulmus alata	Winged Elm	T-r; P-m; S-m
Ulmus rubra	Slippery Elm	T-m; P-m; S-m;T-r; P-r; S-r
Vaccinum pallidum	Lowbush Blueberry	B-m
Viburnum prunifolium	Black Haw	P-m
Viburnum spp.	Viburnum	B-m; B-r
Vitis spp.	Grape Vine	V-m; V-r
Wisteria spp.	Wisteria	V-m; V-r

[1]Growth form and habitat key

<u>Growth Form</u>
T = Tree, ≥ 12.5 cm DBH
P = Pole, ≥ 2.5 and < 12.5 cm DBH
S = Sapling
B = Bush
V = Vine

<u>Habitat</u>
R = Riparian
M = Mesic

[2]Oak Groups *sensu* Peterson Field Guide Series (Petrides, 1988)

Appendix H
Means, Ranges, and Standard Deviations of Canopy and Edge Closure Measurements and Canopy Height Measurement by Quadrat

	Canopy Ht. (m)	Canopy Closure (%)[1]			Edge Closure (%)[1]		
ID#	Single Measurement	Mean	Range	Std. Dev.	Mean	Range	Std. Dev.
1M	15.2	87	80-90	4.1	42	5-90	40.5
2M	19.8	85	80-90	3.9	50	5-85	33.7
3M	19.8	86	80-90	4.1	45	40-80	22.8
4M	22.9	91	85-95	4.1	69	55-95	19.8
5M	15.9	79	70-90	8.2	39	5-65	24.3
6M	19.8	91	90-95	2.2	64	50-85	13.4
7M	18.3	86	75-90	1.8	68	40-85	18.2
8M	18.2	82	85-90	2.7	66	40-90	20.3
9M	18.9	86	80-90	4.1	71	50-90	14.3
10M	21.3	87	80-90	4.5	47	10-90	34.5
11M	17.8	83	80-90	4.5	60	40-75	13.7
12M	22.8	84	60-90	1.1	39	20-50	12.4
13M	22.8	85	70-90	8.6	49	30-65	16.3
14M	15.2	80	70-95	7.9	60	45-80	16.2
15M	18.9	91	90-95	2.2	79	60-90	8.2
1R	15.2	87	80-90	3.7	69	40-90	22.4
2R	20.4	87	85-90	1.9	89	85-90	4.1
3R	17.4	84	80-90	4.2	71	15-95	32.8
4R	16.8	85	80-90	5.0	84	65-95	11.4
5R	15.8	69	50-80	13.4	76	65-90	10.8
6R	15.2	70	50-90	14.5	67	10-95	35.4
7R	15.3	54	40-70	13.4	63	10-90	28.8
8R	16.6	82	70-95	7.9	88	75-95	8.3
9R	12.2	84	70-90	7.8	87	75-90	7.5
10R	19.5	72	55-90	15.2	48	5-80	35.2
11R	15.2	82	70-90	7.5	92	80-95	7.0
12R	15.2	81	75-90	6.5	89	80-95	5.4
13R	10.7	81	75-85	5.0	83	65-95	12.5
14R	15.2	89	85-90	2.2	76	40-90	20.7
15R	15.2	85	85-90	0	49	15-90	36.6

[1]Mean and range of five measurements taken within each quadrat. For additional information regarding methodology, see Section 4.0.

Appendix I
TWINSPAN Two-Way Table[1]

```
          2211222231222121 111    1    1
          237860581094697203234168154795

robips    ----------34354-----------3---  00000
quemue    ---3------455-----------------  000010
carova    -----------5------------------  000010
oxyarb    ----------3-------------------  000010
aesfla    -----------3------------------  000010
fraame    --------2-4-4--4--------------  000011
cercan    --------------2---------------  000011
carcor    ---------------3--------------  000011
querub    ---35555445255----------------  00010
lirtul    ----4-4--4-3--55--------------  00010
quealb    ---5------5-------------------  00010
ostvir    ------5-4----5----------------  00010
queste    ---33-------------------------  00011
pinvir    ---5-4------------------------  00011
junvir    ----45453------3---2----------  0010
quefal    --------2---------------------  0010
pruser    --------4---------------------  0010
tilame    ---------5--------------------  0010
cargla    --5---4-----------------------  001100
faggra    --43--------------------------  001100
quemar    -5--44------------------------  001100
cartom    -5-3--------------------------  001100
asitri    -5----------------------------  001100
diovir    4--------------4--------------  001101
liquid    54-3----4-----5-5-------------  00111
acerub    435----------------------4----  01
ulmrub    --------543-----5-----43------  10
celtis    -----------2--3-----------5---  10
platan    ------------43-4---55545443--3  110
pintae    -------------3-----------4----  110
betnig    ----------------3-535---34--4-  1110
acesai    ----------------45543355555555  1110
frapen    ----------------45543--------3  1110
morrub    ---------------------3--3-----  1110
salixn    -------------------5-------5-4  1111
aceneg    ------------2-------------3-43  1111

          000000000000000111111111111111
          000111111111111100000000001111
             0000000111111000001111
             0111111000011011110000 1
              000011
```

[1]Quadrat numbers along the top: 1 - 15 = 1R - 15R and 16- 30 = 1M - 15M; species names along the left side of the table; zeros and ones on the right and bottom sides define the dendogram of the classification of species and quadrats, respectively; and the interior of the table contains the abundance class of each species in each quadrat.

VITA

Ruth Anne Hanahan, a native of Knoxville, Tennessee, received her Bachelor of Science in Biology from Belmont Abbey College, Belmont, North Carolina in 1982. In 1983, she returned to Knoxville in 1983 and entered the Graduate Program in Public Health Nutrition at the University of Tennessee. She received a Master of Science in Nutrition in December, 1983.

After completing a dietetic residency at Alton Oschner Medical Foundation, Ms. Hanahan moved to Charleston, South Carolina where she developed nutrition and fitness-related programs at the Medical University of South Carolina. In 1990, she returned to Knoxville and worked as a nutrition and fitness consultant. Her clients included area hospitals and, later, Department of Energy (DOE) contractors. In conjunction with her work with DOE contractors, she developed and implemented environmental, safety and health compliance training programs. In 1992, she began working for Battelle Memorial Institute in Oak Ridge where she continued developing training programs and assisting DOE facilities in complying with environmental regulations.

As a result of her work with Battelle, Ms. Hanahan decided to pursue a degree in the environmental field. In 1994, she entered the Graduate Program in Ecology at the University of Tennessee and was awarded a research assistantship in the University of Tennessee Energy, Environment, and Resources Center which she retained throughout the graduate program. In 1996, she received a Master of Science in Ecology. Ms. Hanahan has also continued to maintain her dietetic registration (R.D.) and State of Tennessee Board of Nutritionists certification.